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CONSULTING GEOTECHNICAL AND MINING ENGINEERS

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INSITU STRESS DETERMINATION IN NO. 26 COLLIERY CAPE BRETON NOVA SCOTIA

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ABSTRACT

A program of insitu stress determination for No. 26 Colliery of the Sydney coalfield in Cape Breton was completed in December 1983. The measurements were undertaken in three 100 mm diameter drillholes located at the north end of the main deeps, approximately 300 m from the boundary of the current mining development area. The insitu stresses were measured by the method of overcoring using the USBM deformation gauge.

A total of nine overcoring tests were attempted of which five were completely successful. The test data was used to evaluate: (a) the secondary principal stresses(for individual tests) on a plane perpendicular to the drillhole axis for the case of plane strain, and (b) the average stress tensor in the rock strata by applying the method of least squares.

The results of the least squares solution indicate that there is good correlation between independent measurements carried out in three separate drillholes.

The state of insitu stresses in the rock strata tested is fairly isotropic with very low shear stresses. The major principal stress is 26.30 MPa and oriented in the EW direction at an inclination of 25 degrees. The ratio of the major and minor principal stresses is about 1.1. The average vertical stress component measured at the test site is about 15 percent higher than the static vertical stress.

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On mit la dernière main, en décembre, à un programme de détermination de la tension in situ pour la houillère n° 26 du bassin houiller de Sydney au Cap Breton. On prit les mesures dans trois trous de forage d'un diamètre de 100 mm situés a l'extrémité nord des cavités principales, soit à environ 300 m de la limite de la zone de développement de la mine actuelle. On mesura les tensions in situ grâce à la méthode de sur-carottage où l'on utilise la jauge de déformation USBM.

On pratiqua un nombre total de neuf essais de sur-carottage dont cinq s'avérèrent parfaitement réussis. On utilisa les informations tirées de ces essais pour évaluer: (a) les tensions principales secondaires (relatives aux essais individuels) appliquées sur un plan perpendiculaire à l'axe du trou de forage en cas de déformation de plan, et (b) le tenseur de tension moyenne dans les couches de rocks en appliquant la méthode des moindres carrés.

Les résultats de la solution des moindres carrés indiquent qu'il existe une bonne corrélation entre les mesures indépendantes provenant des trois trous de forage distincts.

L'état des tensions in situ dans les couches de rocs analysées est relativement isotropique et présente très peu de tension de cisaillement. La tension principale majeure est de 26.30 MPa et orientée dans la direction EO selon un angle de 25 degrés. Le rapport des tensions principales majeure et mineure est d'environ 1.1. La composante de la tension verticale moyenne mesurée sur le site d'essai est supérieure d'environ 15 pour cent à celle de la tension verticale statique.

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1. INTRODUCTION

No. 26 Colliery is one of the producing mines of the Sydney coalfield owned and operated by the Cape Breton Development Corporation (CBDC) in Cape Breton, Nova Scotia. A study of the ground control problems (such as floor heave and roof instability) in this mine is being undertaken by the Cape Breton Coal Research Laboratory (CBCRL). To obtain the ground stress data for this research study, a test program was proposed by CBCRL to measure the insitu stresses in the rock strata in the vicinity of the mine workings.

Golder Associates was awarded a contract under the auspices of CANMET through Supply and Services Canada (DSS Contract No. 0SQ83-00173) to undertake this measurement program. The terms of reference were to carry out overcoring tests in three separate drillholes using the USBM deformation gauge.

2. TEST LOCATIONS AND GEOLOGICAL CONDITIONS

No. 26 Colliery is a sub-sea coal mine located about 5 km offshore from Glace Bay (see Figure 1). The mining development area extends approximately 6 km in the E-W and 3 km in the N-S direction (with reference to the mine co-ordinate system) and is currently proceeding in a northerly direction following the Harbour coal seam which has an average dip (downward) of about 5 degrees. Longwall mining technique is being used for the coal extraction.

The site for insitu stress determination was located at the north end of the main deeps, approximately 300 m from the boundary of the current mining development area. Overcoring tests were carried out in three (3) 100 mm dia. (H size) holes drilled from a 3.7 m wide development level off the main deeps at orientations and inclinations shown on Figure 2. In general, tests in each drillhole were commenced about 10 m from the hole collar so that the test positions are outside the zone of influence of the development level. The depth of the drillholes and the test positions are summarized in Table 1.

At the test site, the coal seam extends to about 1 m above the floor of the level. It is overlain by a siltstone strata comprising fresh, laminated, medium grey, very fine grained sandy siltstone. Drillholes 1 and 2 were located in this siltstone layer. An N size exploration hole was drilled slightly above the position of drillhole No. 1 to confirm the rock strata prior to commencement of the testing program.

Overlying the siltstone, a sandstone channel (according to interpretation by CBDC geologist) was encountered. This layer consists of fresh, laminated to moderately bedded, light to medium grey, fine to medium grained sandstone with occasional black carbonaceous partings. Tests in drillhole 3 were positioned within this sandstone unit.

According to the geological data provided by CBDC, the test site is located in a generally uniform geological environment with no dominant geological structures (such as faults) in the vicinity of the mining block.

3. TEST PROCEDURE AND EQUIPMENT

3.1 General Test Procedure

In this test program, the insitu stresses were measured by the method of overcoring developed by the United States Bureau of Mines (USBM) (Hooker and Bickel 1974). The techniques were slightly modified to suit the present program. The field work was completed during December 1983.

The general procedure of the overcoring method is illustrated on Figure 3. A 100 mm diameter (H size) hole was drilled to about 250 mm short of the required location for the stress measurement test. A 38 mm diameter (EX size) pilot hole (approximately 600 mm in length) concentric with the 100 mm diameter hole was drilled through the test position. The USBM deformation gauge was then installed in the pilot hole in an area free of joints or fractures, normally at 200-300 mm from the end of the 100 mm diameter hole. The pilot hole was then overcored using a 100 mm diameter thin-walled coring bit to relieve the stresses around the pilot hole. The corresponding changes in the diametral deformations in the pilot hole were monitored during overcoring using the USBM deformation gauge connected to a digital strain indicator, and a switch and balance unit. The stresses were evaluated from the measured changes in the deformations, and the deformation modulus determined by testing the overcored rock specimen.

3.2 USBM Deformation Gauge

The USBM deformation gauge (see Figure 4) is designed to measure the changes in the deformation of the pilot hole across three diameters (spaced 120° apart). The gauge has three pairs of buttons (see Figure 4) which provide contact

between the surface of the pilot hole and the sensing element of the gauge. Continuous observation of the borehole deformation changes can be made during overcoring. This instrument enables the measurement of the two-dimensional stress field on a plane normal to the axis of the drillhole. Details of this instrument and the operational procedure have been described by Hooker and Bickel (1974). The calibration of the USBM gauge used for this project is presented in Appendix A.

3.3 Biaxial Testing Equipment

The deformation modulus of the rock at the test position was determined using a "biaxial test cell", the set up of which is shown on Figure 5. The cell essentially consists of a cylindrical steel jacket and seals. The overcored rock specimen recovered from the test position is tested in the cell with the USBM gauge inside the specimen. Hydraulic oil is pumped into the space between the steel jacket and the sealed membrane which is in contact with the overcore. The outer surface of the overcore is therefore subjected to a uniformly distributed radial (biaxial) pressure. During modulus testing, the deformations of the inner hole of the overcore are monitored at various pressure increments and decrements. The calibration of this equipment is presented in Appendix B.

3.4 Drilling Equipment

The stress measurement drillholes were drilled using a Longyear 38 underground drill supplied by the Cape Breton Development Corporation. The general arrangement and set up of the drill rig at the test site is shown on Figure 6.

Since drilling is the most expensive component of stress determination, a 100 mm diameter (H size) drillhole was used so that more readily available standard drilling equipment could be used. Apart from the standard HQ wireline equipment used for drilling the H size borehole, specialized ancillary drilling equipment was used to facilitate the drilling of the pilot hole and the overcoring operation. A list of the specialized drilling equipment and an outline of the procedure in using this equipment is given in Appendix C.

3.5 Certification of Testing Equipment

In compliance with the statutory requirements of the Coal Mines (CBDC) Safety Regulations, all electrical equipment (including their circuitries) and installation tools used for stress measurements were certified by the Mining Research Laboratories of CANMET. This set of equipment was also approved by Labour Canada (Sydney).

4. RESULTS OF TESTS

4.1 General

A total of nine (9) overcoring tests were attempted during this series of stress measurement, four (4) in drillhole 1, three (3) in drillhole 2 and two (2) in drillhole 3. However, not all of these attempts were successful due primarily to premature breakage (prior to completion of the desired depth of overcoring) of the rock during some of the overcoring tests. There was a tendency for the cores to split along the bedding planes and other planes of weakness when the stresses around the drillhole were relieved. The test positions in each drillhole and the problems, if any, encountered during testing are summarized in Table 1. Results of the overcoring and biaxial tests are presented in the following sections.

4.2 Results of Overcoring Tests

During the overcoring tests, the diametral deformation of the pilot hole was monitored. The measured diametral deformations (as calculated from the recorded strain readings using the calibration factors presented in Appendix A) for the three button positions (designated as U1, U2, and U3 respectively) are plotted against the depth of overcoring measured from the collar of the pilot hole. The results from USBM 2 to USBM 9 are presented on Figures 7 to 14 respectively. No data was available from USBM 1 since it was aborted due to problems described in Table 1.

There is some degree of uncertainties in the results of USBM 2 because breakage of the core occurred close to (but beyond) the button positions during overcoring. This would typically give rise to a larger measured diametral deformation which will continue until overcoring stops. This trend is reflected in the test data shown on Figure 7.

Results of USBM 3 (Figure 8) and USBM 8 (Figure 13) are also typical of unsuccessful overcoring tests where rock breakage occurred before the overcoring bit reached the gauge button positions. As a result of the rock breakage at USBM 3, the instrument in the pilot hole was caused to rotate with the overcore and has thus sustained considerable damage to the instrument cable.

Tests that were completely successful included USBM 4 to USBM 7 and USBM 9. Results of these tests (Figures 9 to 12 and Figure 14) displayed the classical response curves of good, successful tests. Typically, the readings were stable during the initial stages and showed distinct changes when the overcore bit approached and subsequently passed the button positions. The readings again became stable as overcoring continued beyond the button positions. Based on the plots shown on Figures 9 to 12 and Figure 14, the total diametral deformations of the pilot holes for each of the successful overcoring tests are summarized in Table 3.

4.3 Results of Biaxial Tests

Due to the laminated nature of the siltstone, the overcore has a tendency to split along the laminations. Even if the core remained intact during overcoring, splitting occurred in some of the overcores when they were retrieved. Consequently, only three (3) pieces of intact overcores were recovered, two from drillhole 1 (siltstone samples) and one from drillhole 3 (sandstone samples).

The results of the biaxial tests on these overcores are shown on Figures 15 to 17 in which the diametral deformations of the pilot hole at the three button positions are plotted with respect to the applied radial (biaxial) pressures on the overcore.

In general, the curves of deformation vs. pressure are fairly linear and show little hystersis upon unloading. The variation between the diametral deformations measured in any one of the biaxial tests is within 30 percent of the maximum diametral deformation for that particular test . During the biaxial tests, the USBM gauge was consistently oriented with button set no. 1 placed within a plane perpendicular to the bedding of the strata. However, it was noted from the test results that there was no preferential direction along which maximum diametral deformation occurred.

4.4 Evaluation of Elastic Constants and Insitu Stresses

4.4.1 Evaluation of Elastic Constants

The deformation modulus of the rock was evaluated based on the results of the biaxial tests using the following expression and assuming isotropic elasticity.

$$E = \frac{4ab^2P_o}{(b^2-a^2)U}$$

where E = Deformation modulus
a = the inner radius of the overcore
b = the outer radius of the overcore
P_o = pressure on the outer surface of the overcore
and U = Diametral deformation of pilot hole in the overcore

Where the deformations across the three diameters varied, the average diametral deformation was used for the evaluation of the average deformation modulus. The effects of anisotropic deformation of the rock on the evaluation of the insitu stresses are discussed in Section 5. The average deformation modulus of the samples recovered from the overcoring tests are summarized in Table 2.

Poisson's ratio of the rock was not measured directly from the biaxial test using the USBM gauge. A value of 0.2 was assumed for the Poisson's ratio for the purpose of stress evaluation.

4.4.2 Evaluation of Insitu Stresses

The interpretation of the overcoring test data is based on the assumption that the rock is homogeneous and linearly elastic. Two interpretation procedures are considered in this report:

(a) Evaluation of the secondary principal stresses on a plane perpendicular to the axis of the borehole assuming that the stress changes during overcoring occur under plane strain condition.

(b) Evaluation of the complete three-dimensional stress system by pooling all the data and using a least squares solution for the complete stress tensor. The orientations of the drillholes and diametral deformation measurements are taken into account in this interpretation.

Outlines of the above data reduction procedures are described in Appendix D. In both cases, the diametral deformation, the rock deformation modulus and the Poisson's ratio are used for the analysis. The secondary principal stresses calculated by the procedure described in (a) and in Appendix D are summarized in Table 3. The input parameters and the results of the insitu stresses evaluated by the procedure described in (b) are presented in Table 4. The results include:

- The six independent stress components σ_x, σ_y, σ_z, τ_{xy}, τ_{yz} and τ_{zx} with respect to the mine co-ordinate system (x, y and z correspond to EW, NS and the vertical directions respectively).

- The standard deviations of the stress components and the correlation coefficient of the multilinear regression analysis in the least squares solution.

- The magnitudes and directions of the principal stresses based on the average values of the six stress components.

5. DISCUSSION OF TEST RESULTS

5.1 Effects of Anisotropic Characteristic of Rock on the Interpretation of the Test Results

The results of the biaxial tests presented in Section 4 indicated that there were slight variations in the deformations across the three diameters of the pilot hole under a given uniform radial pressure. The maximum variation as noted from the tests was within 30 percent. However, it was also noted from the results that there was no preferential direction along which maximum deformation occurred.

A comparison of the isotropic and anisotropic interpretation of the state of insitu stresses has been given by Becker and Hooker (1976). The order of error that may be made in determining the stresses in anisotropic rock by using isotropic expressions was also examined.

Based on the results of their study, it is noted that for an approximately isotropic stress field, the errors involved in determining the state of stress by using isotropic expressions are insignificant for the degree of anisotropy observed in the present tests. Hence, it is acceptable to use the average deformation modulus from the biaxial test for the evaluation of insitu stresses for the present study.

5.2 State of Insitu Stresses

The determination of the complete stress tensor by the least squares solution takes into account the effect of axial stress along the drillholes. It is noted that the stresses evaluated by this procedure are about 7 percent higher than those based on the case of zero axial strain.

The results presented in Table 4 indicate that there is good correlation between the independent measurements made in three separate drillholes on the basis of the high coefficient of correlation of the regression line and the low magnitude of the standard deviations.

The average magnitudes of the six independent stress components indicate that the state of insitu stresses in the vicinity of the test site is fairly isotropic with very low shear stresses. The average vertical stress component (σ_z) is 25.27 MPa. A comparison of the measured vertical stress and the static vertical stress (σ_v) was made and the results are summarized below:

(i) Average vertical stress (σ_z) calculated from least squares solutions (Table 4) = 25.27 MPa (standard deviation = 1.16 MPa)

(ii) Static vertical stress (σ_v) calculated on the basis of the following parameters:

- Depth of test site below seabed = 762 m (2500 ft.)
- Depth of sea at test site = 90 m
- Density of rock = 2.72 Mg/m^3
- Density of seawater = 1.025 Mg/m^3

Hence vertical static stress (σ_v) = 21.7 MPa

It may be noted that the average measured vertical stress is about 15 percent higher than the static vertical stress. This is within the range of variations of the results of vertical stresses measured in Canada and in other parts of the world (Hoek and Brown, 1980).

It may also be noted from the secondary principal stresses (Table 3) that the magnitudes of insitu stresses in the siltstone and sandstone units are reasonably consistent despite a substantial difference (by a factor of 2.6) between the deformation moduli of these two rock types.

The principal stresses and the direction of the principal axes are presented in Table 4C. The major principal stress is 26.30 MPa and acts in the EW direction (with reference to the mine grid) at an inclination of 25^{o}. The ratio of the major and minor principal stresses is about 1.1. Since the test site is located sufficiently far (300 m) from the boundary of the current mining development area and the zone of influence of the development level (see Figures 1 and 2), the insitu stresses measured in this program should represent the virgin insitu stresses existing in the siltstone and sandstone strata.

6. CONCLUSIONS

The insitu stress measurement program for No. 26 Colliery of the Sydney coalfield in Cape Breton was completed in December 1983. A total of nine USBM overcoring tests were undertaken in three 100 mm diameter, sub-horizontal to inclined drillholes located in the siltstone and sandstone strata at the northern end of the main deeps. The conclusions derived from this test program are summarized below.

(a) Of the nine USBM tests undertaken, five of the tests were completely successful. The unsuccessful attempts were primarily the results of premature rock breakage along bedding planes or planes of weakness during overcoring.

(b) Based on the results of the biaxial tests, the rock tested showed a slight anisotropic deformation characteristic. Such degree of anisotropy, however, is not significant enough to affect the interpretation of the stresses by using isotropic expressions.

(c) Despite a substantial difference between the deformation moduli of siltstone and sandstone (by a factor of 2.6), the magnitudes of the measured stresses are reasonably consistent.

(d) The results of the least squares solution for the stress tensor indicate that there is good correlation between the independent measurements carried out in three separate drillholes.

(e) The state of insitu stresses in the rock strata is fairly isotropic with very low shear stresses. The major principal stress is 26.30 MPa and oriented in the EW direction at an inclination of 25 degrees. The ratio of the major and minor principal stresses is about 1.1. The average vertical stress component measured at the test site is about 15 percent higher than the static vertical stress calculated from the weight of the rock and water above the test location. This is within the range of variations of the vertical stresses measured in Canada and other parts of the world.

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GOLDER ASSOCIATES

C.M.K. Yuen, P. Eng.

S.D. McKinnon, P. Eng.

for J.L. Gilby

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TABLE 1 - SUMMARY OF POSITIONS OF OVERCORING TESTS

DRILL HOLE	ROCK TYPE	DRILL HOLE ORIENTATION		TEST NO.	DEPTH OF TEST FROM HOLE COLLAR (m)	COMMENTS ON TESTS
		AZIMUTH	DIP			
1	Siltstone	330° (N30°W)	4°	USBM 1 USBM 2 USBM 3 USBM 4	10.69 11.73 12.75 15.14	a, e b c d, e(1)
2	Siltstone	60° (N60°E)	4°	USBM 5 USBM 6 USBM 7	11.18 11.84 12.50	d d d
3	Sandstone	60° (N60°E)	30°	USBM 8 USBM 9	9.4 11.15	c d, e

1. COMMENTS ON TESTS:

   a. Test was aborted when USBM gauge was pushed out of the pilot hole due to a surge of water pressure during overcoring (negligence of drill operator).
   b. Rock broke close to (beyond) the USBM gauge button.
   c. Rock broke before overcoring bit reached USBM gauge button. Gauge rotated with overcore.
   d. Successful test.
   e. Intact overcore samples recovered from test position.
   e(1) Intact overcore sample recovered between USBM 3 and USBM 4.

2. NOTES:

   Azimuth is referenced to mine co-ordinate system. Positive dip is upward.

TABLE 2

SUMMARY OF RESULTS OF BIAXIAL TESTS

DRILL HOLE	ROCK TYPE	BIAXIAL TEST NO.	DEPTH OF SAMPLE FROM HOLE COLLAR (m)	AVERAGE MODULUS OF DEFORMATION (GPa)
1	SILTSTONE	1	10.70	33.7
1	SILTSTONE	2	13.80	35.5
3	SANDSTONE	3	11.15	13.1

NOTE: All samples were tested dry.

TABLE 3 MAGNITUDES AND DIRECTIONS OF SECONDARY PRINCIPAL STRESSES MEASURED FROM OVERCORING TESTS

DRILL HOLE	ROCK TYPE	TEST NO.	DEPTH OF TEST FROM HOLE COLLAR (m)	DIAMETRAL DISPLACEMENT OF PILOT HOLE (micro inch)			SECONDARY PRINCIPAL STRESSES		ORIENTATION OF P FROM DIRECTION OF U1	ELASTIC CONSTANTS FOR THE EVALUATION OF STRESSES	
				U1	U2	U3	MAX. STRESS P (MPa)	MIN. STRESS Q (MPa)		E(GPa)	ν
1	SILT-STONE	USBM 4	15.14	2058	2010	1885	24.34	23.17	22°	34.6	0.2
2	SILT-STONE	USBM 5	11.18	2000	1610	1975	23.79	20.75	331°	34.6	0.2
		USBM 6	11.84	2000	1605	1870	23.24	20.48	339°	34.6	0.2
		USBM 7	12.50	2455	2110	2045	27.92	24.82	4°	34.6	0.2
3	SAND-STONE	USBM 8	11.15	3460	5095	5850	25.03	18.62	279°	13.1	0.2

NOTES:
1. Diametral displacements are presented in microinches using the following calibration factors:
   Button no. 1 = 1.00 (microinch for unit microstrain)
   Button no. 2 = 1.01
   Button no. 3 = 1.01
2. In each test, button set no. 1 was oriented within the vertical plane through the axis of the drill hole.
3. Only data from successful overcoring tests are used for the calculation of insitu stresses.
4. P and Q are respectively the maximum and minimum stresses (secondary principal stress) measured on the plane perpendicular to the axis of the drill hole.
5. Orientation of P is measured counterclockwise from the U1 direction.
6. E values are determined from biaxial tests (see Table 2); ν is assumed.
7. Orientations of the drill holes are shown in Table 1.

TABLE 4

STRESS TENSOR CALCULATED BY
LEAST SQUARES SOLUTION

a. INPUT PARAMETERS

DRILL HOLE	DRILL HOLE ORIENTATION		TEST NO.	DIAMETRAL DEFORMATION (microinch)			ELASTIC CONSTANTS	
	AZIMUTH (α)	DIP (Ψ)		U3 ($\theta=0^{\circ}$)	U1 ($\theta=90^{\circ}$)	U2 ($\theta=150^{\circ}$)	E (GPa)	ν
1	330°	4°	USBM 4	1885	2058	2010	34.6	0.2
2	60°	4°	USBM 5	1975	2000	1610	34.6	0.2
			USBM 6	1870	2000	1605	34.6	0.2
			USBM 7	2045	2455	2110	34.6	0.2
3	60°	30°	USBM 9	5850	3460	5095	13.1	0.2

NOTE: 1. θ is the angle between the h_1 axis of the drill hole and the diameter across which the deformation was measured (see Figure D.1 in Appendix D for notation of co-ordinate system for drillhole).

2. Only data from successful overcoring tests are used in the least squares solution.

3. E values are determined from biaxial tests (see table 2); ν is assumed.

TABLE 4 (cont'd)

b. RESULTS OF LEAST SQUARES SOLUTION

(i) AVERAGE STRESS TENSOR

$\sigma_x (\sigma_{E-W})$	= 23.31 MPa	τ_{xy}	= 0.01 MPa
$\sigma_y (\sigma_{N-S})$	= 24.98 MPa	τ_{yz}	= -0.05 MPa
σ_z	= 25.27 MPa	τ_{zx}	= 1.21 MPa

(ii) STATISTICAL INTERPRETATION

- Coefficient of Correlation: R = 0.99
- Standard Deviation of Regression Line: S = 288 microinches
- Standard Deviations of the Stress Components:

$s(\sigma_x)$	= 3.26 MPa
$s(\sigma_y)$	= 2.97 MPa
$s(\sigma_z)$	= 1.16 MPa
$s(\tau_{xy})$	= 1.80 MPa
$s(\tau_{yz})$	= 0.93 MPa
$s(\tau_{zx})$	= 1.15 MPa

c. MAGNITUDES AND DIRECTIONS OF PRINCIPAL STRESSES

PRINCIPAL STRESSES	AZIMUTH	DIP
S1 = 26.30 MPa	270°	-25°
S2 = 23.20 MPa	278°	64°
S3 = 24.05 MPa	90°	-13°

NOTES: - Azimuth is referenced to mine co-ordinate system
- Positive dip is upward.

APPENDIX A

CALIBRATION OF USBM GAUGE

Appendix A - Calibration of USBM Gauge

Calibrations of the USBM gauge were carried out before and after the stress measurement using the set up shown on Figure A.1. The average calibration factors were used in the reduction of the test results. Typical results of the calibrations are presented in Table A1 below:

TABLE A.1

CALIBRATION OF USBM DEFORMATION GAUGE

Instrument No: USBM 2
Strain Indicator: P350A Gauge Factor: 0.4
CALIBRATION - December 28, 1983

	BUTTON NO. 1 (U1)		BUTTON NO. 2 (U2)		BUTTON NO. 3 (U3)	
Displ. (mm)	Instr. Rdg. (micro strain)	Difference Δ (micro strain)	Instr. Rdg. (micro strain)	Difference Δ (micro strain)	Instr. Rdg. (micro strain)	Difference Δ (micro strain)
0	0	3752	0	3756	0	3835
0.1	3752	3851	3765	3799	3835	3861
0.2	7603	3920	7555	3859	7696	3849
0.3	11523	3794	11414	3986	11545	3857
0.4	15317	4010	15400	3890	15402	3858
0.5	19328	4018	19290	3947	19260	3796
0.6	23346	4309	23237	3997	23056	3870
0.7	27455	4483	27234	3973	26926	4291
0.6	22972	4194	23261	3977	22635	3972
0.5	18778	4030	19284	3924	18663	3917
0.4	14748	3856	15360	3974	14746	3778
0.3	10892	3747	11381	3888	10968	3791
0.2	7145	3680	7498	3718	7177	4279
0.1	3465	3430	3780	3730	3438	3254
0	35		50		184	
	Av = 3933		Av = 3887		Av = 3872	

Average Calibration Factor: (Displacement in micro inches per microstrain)

Button No. 1 = 1.00
Button No. 2 = 1.01
Button No. 3 = 1.01

FIGURE A.1 EQUIPMENT FOR CALIBRATING USBM GAUGE

APPENDIX B

CALIBRATION OF BIAXIAL TEST EQUIPMENT

B.1 CALIBRATION OF BIAXIAL TEST EQUIPMENT

The biaxial test equipment was calibrated by testing a hollow aluminum cylinder of known elastic properties. The USBM gauge was used to measure the deformation of the aluminum cylinder following the test procedure outlined in Section 3.3.

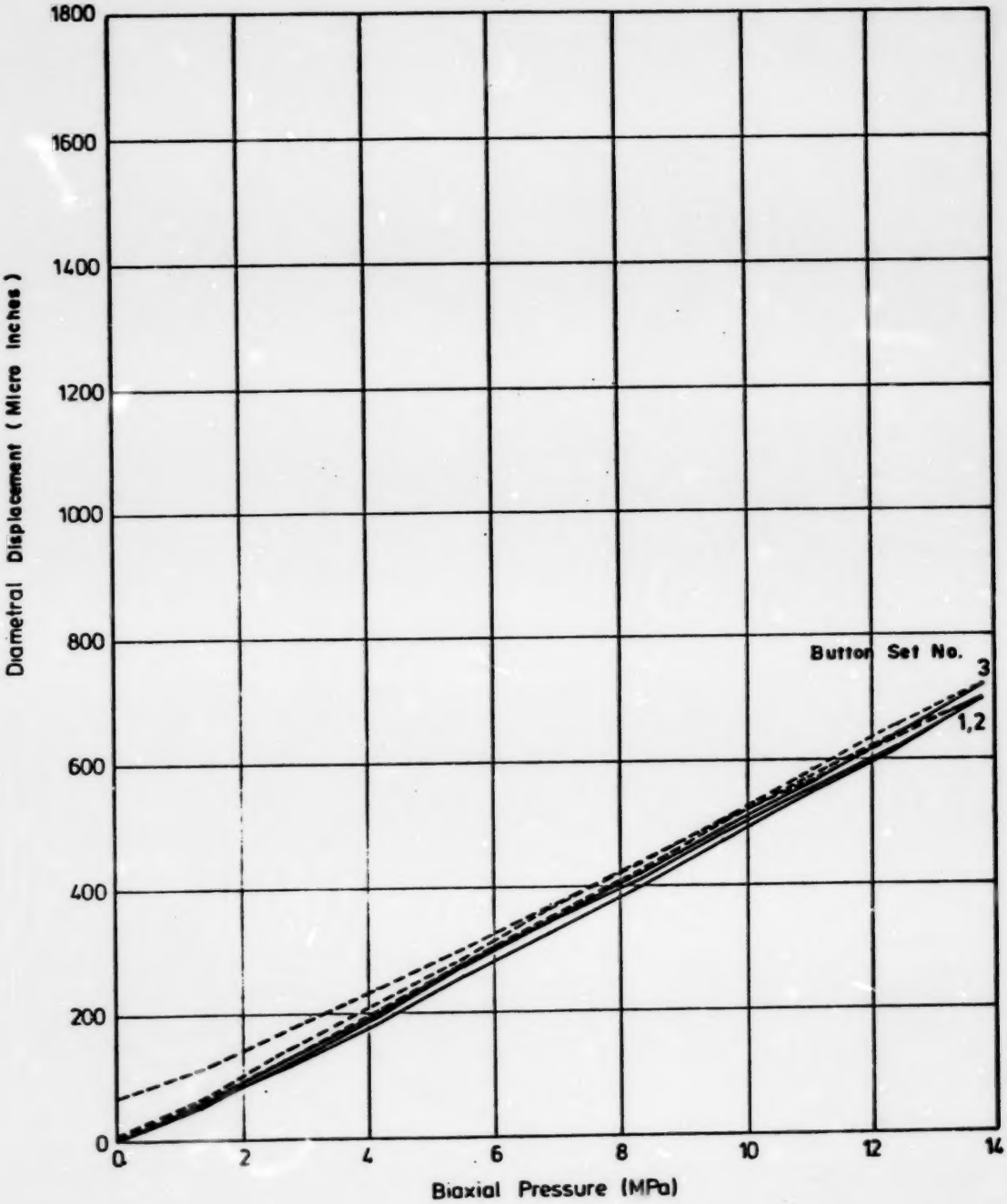
Based on the results of the calibration tests shown on Figure B.1, the deformation modulus of aluminum is:

Button Set No.	Deformation Modulus of Aluminum
1	72.89 GPa
2	72.89 GPa
3	72.48 GPa
	Av. 72.75 GPa

The calibration specimen was prepared from aluminum 2024-T351. The specified modulus of elasticity for this alloy is 73.09 GPa. The difference between this and the average deformation modulus shown above is less than 0.5 percent.

USBM ALUMINUM CALIBRATION CYLINDER TEST
BIAXIAL TEST RESULTS

FIGURE B.1



Date JAN. 27, 1984
Project 831-1296

Golder Associates

Drawn JLG
Chkd

APPENDIX C

SPECIALIZED DRILLING EQUIPMENT FOR OVERCORING

APPENDIX C - SPECIALIZED DRILLING EQUIPMENT FOR OVERCORING

The equipment described in this Appendix pertains to overcoring using a 100 mm diameter hole and a 38 mm diameter pilot hole. The overcoring equipment was designed to adapt to the commercially available HQ wireline drilling equipment and can be used either in horizontal or vertical down holes. The components of the drilling equipment are as follows:

(a) Underground drill rig capable of driving HQ equipment such as the Longyear 38 or equivalent.

(b) Water pump complete with pressure gauge readable to 1 psi.

(c) Special water swivel and water pressure regulator (to limit pressure to 40 psi).

(d) Standard HQ wireline drilling equipment with HQ driving rods.

(d) Modified inner tube assembly for the HQ system which carries the starter barrel for the E hole and the 1 m longer double tube E core barrel. This modified assembly latches in place of the conventional HQ inner tube assembly and is rotated and/or fed when the HQ rods are rotated and/or fed. As the modified inner tube assembly was machined to set concentrically with the HQ outer tube, the E hole drill with this assembly would be concentric with the H hole.

This system of drilling is especially advantageous when carrying out deep measurements in vertical downholes because the wireline system allows substantial saving

in the time for breaking up and assembling drill rod for drilling the holes. This system has been used successfully in stress measurements in Nova Scotia and Ontario.

(f) 100 mm diameter thin-walled overcoring bit adaptable to and driven by HQ rods acting as a continuous string of stabilizers along the drillhole. This eliminates the use of individual stabilizers and hence improves the efficiency.

(g) Core chisel and core retriever adaptable to EW rod for easy handling.

The above equipment performed satisfactorily during the tests.

APPENDIX D

PROCEDURES FOR EVALUATION OF INSITU STRESSES FROM OVERCORING TEST DATA

February 1984

831-1296

D.1 EVALUATION OF SECONDARY PRINCIPAL STRESSES FROM OVERCORING TEST DATA

Based on the deformations measured across the three diameters, the secondary principal stresses on the plane perpendicular to the axis of the drillhole are given by the following expressions(Obert and Duvall, 1967).

$$P = \frac{E}{6d(1-\nu^2)} \left(U_1+U_2+U_3 + \frac{1}{\sqrt{2}} \left[(U_1-U_2)^2 + (U_2-U_3)^2 + (U_3-U_1)^2\right]^{\frac{1}{2}}\right)$$

$$Q = \frac{E}{6d(1-\nu^2)} \left(U_1+U_2+U_3 - \frac{1}{\sqrt{2}} \left[(U_1-U_2)^2 + (U_2-U_3)^2 + (U_3-U_1)^2\right]^{\frac{1}{2}}\right)$$

where E is the average deformation modulus.
ν is the Poisson's ratio.
d is the diameter of the pilot hole
and U_1, U_2, U_3 are the measured changes in borehole diameter across three diameters at 60° rotation.
U is positive for an increasing diameter.
P is the maximum secondary principal stress.
Q is the minimum secondary principal stress.

The direction of P is given by:

$$\theta = \frac{1}{2} \tan^{-1} \left[\frac{\sqrt{3}\ (U_2 - U_3)}{2U_1-U_2-U_3}\right]$$

where θ is the angle to P measured counterclockwise from the direction of the U_1 diameter.

The quadrant of θ may be determined as follows,

if $U_2 > U_3$ and $U_2+U_3 < 2U_1$ then θ is between 0° and 45°

$U2 > U_3$ and $U_2+U_3 > 2U_1$ then θ is between 45° and 90°

$U_2 < U_3$ and $U_2+U_3 > 2U_1$ then θ is between 90° and 135°

$U_2 < U_3$ and $U_2+U_3 < 2U_1$ then θ is between 135° and 180°

The above equations are derived for plane strain condition with zero axial strain ($\varepsilon_2=0$) along the drillhole. If the effect of axial strain is taken into account, an estimate of the axial stress along the borehole is required. Based on the results obtained from the complete solution of the stress tensor, it was noted that the secondary principal stresses based on non-zero axial strain is only about 7 percent higher than those based on zero axial strain.

D.2 EVALUATION OF THE STRESS TENSORS USING LEAST SQUARES SOLUTION

The procedure for using the least squares solution for the stress tensor is described in detail by Panek (1976). The following is an outline of the proposed method.

D.2.1 Formulation of the General Equation for Diametral Deformation

In this formulation, the drillhole is assigned a right hand rectangular co-ordinate system with axis h_1, h_2 and h_3, as shown on Figure D.1. Axis h_2 is parallel to the borehole axis and axis h_3 is vertical if h_2 is horizontal. The three-dimensional stress system with respect to this co-ordinate system is completely defined by the six stress components σ_1, σ_2, σ_3, τ_{12}, τ_{23} and τ_{31}.

Of these six stress components, it may be assumed that the stresses τ_{12} and τ_{23} (or τ_{32}) which act parallel to the axis of the drillhole, have negligible influence on the diametral deformation of the drillhole when the stress system is relieved around the drillhole. Consequently, the diametral change of the drillhole is a function only of the following stress components:

σ_1, σ_3 and τ_{13} acting normal to the drillhole axis,
and σ_2 acting parallel to the drillhole axis

The effect of σ_2 is through the Poissons's effect of the strain ε_2 in the direction of axis h_2.

The contributions to the diametral deformation of the drillholes from σ_1, σ_3, τ_{13} and ε_2 are:

$$U_{(\sigma_1)} = \sigma_1 d (1+ 2 \cos 2\theta)(1-\nu^2)/E \quad (D1)$$

$$U_{(\sigma_3)} = \sigma_3 d (1+ 2 \cos 2\theta)(1-\nu^2)/E \quad (D2)$$

$$U_{(\tau_{13})} = \tau_{13} d (4 \sin 2\theta)(1-\nu^2)/E \quad (D3)$$

$$U_{(\varepsilon_2)} = (\sigma_1 d\nu^2 - \sigma_2 d\nu + \sigma_3 d\nu^2)/E \quad (D4)$$

where U is the deformation across the diameter oriented at the angle θ with respect to the h_1 axis

E is the modulus of deformation

ν is the Poisson's ratio

d is the diameter of the drillhole

θ is the angle with respect to h_1 axis measured in the h_1-h_3 plane

Equations D1 to D4 can be combined to give the total diametral deformation:

$$U = \sigma_1 f_1 + \sigma_2 f_2 + \sigma_3 f_3 + \tau_{13} f_4 \quad (D5)$$

where

$$f_1 = [d(1+ 2 \cos 2\theta)(1-\nu^2) + d\nu^2]/E$$
$$f_2 = -d\nu/E \quad (D6)$$
$$f_3 = [d(1-2 \cos 2\theta)(1-\nu^2) + d\nu^2]/E$$
$$f_4 = d(4 \sin 2\theta)(1-\nu^2)/E$$

D.2.2 Diametral Deformation in a Common Co-ordinate System

When the drillhole deformations are determined from tests in more than one drillhole as in the present case, it becomes necessary to relate all the measurements to a common co-ordinate system. Hence, in addition to the co-ordinate system (h_1, h_2

and h_3) for each drillhole, a set of common co-ordinate system x, y and z should be assigned to the medium. For convenience, x is chosen to be parallel to the EW (East being positive) and y parallel to the NS (North being positive) direction. z is chosen to be the vertical direction (Figure D.1). The six independent stress components of the stress tensor with respect to the x, y, z co-ordinate systems are σ_x, σ_y, σ_z, τ_{xy}, τ_{yz} and τ_{zx}.

The formulae for transformation of stresses in three dimensions may be written as:

$$\begin{bmatrix}\sigma_1\\ \sigma_2\\ \sigma_3\\ \tau_{12}\\ \tau_{23}\\ \tau_{31}\end{bmatrix} = \begin{bmatrix} \ell_1^2 & m_1^2 & n_1^2 & 2\ell_1m_1 & 2m_1n_1 & 2n_1\ell_1 \\ \ell_2^2 & m_2^2 & n_2^2 & 2\ell_2m_2 & 2m_2n_2 & 2n_2\ell_2 \\ \ell_3^2 & m_3^2 & n_3^2 & 2\ell_3m_3 & 2m_3n_3 & 2n_3\ell_3 \\ \ell_1\ell_2 & m_1m_2 & n_1n_2 & (\ell_1m_2+\ell_2m_1) & (m_1n_2+m_2n_1) & (n_1\ell_2+n_2\ell_1) \\ \ell_2\ell_3 & m_2m_3 & n_2n_3 & (\ell_2m_3+\ell_3m_2) & (m_2n_3+m_3n_2) & (n_2\ell_3+n_3\ell_2) \\ \ell_1\ell_3 & m_1m_3 & n_1n_3 & (\ell_1m_3+\ell_3m_1) & (m_1n_3+m_3n_1) & (n_1\ell_3+n_3\ell_1) \end{bmatrix} \times \begin{bmatrix}\sigma_x\\ \sigma_y\\ \sigma_z\\ \tau_{xy}\\ \tau_{yz}\\ \tau_{zx}\end{bmatrix} \qquad \text{(D7)}$$

ℓ_1, m_1, n_1 are the direction cosines for the positive h_1 axis with the positive x, y, z axis. For a given azimuth of drillhole orientation, α, and dip of drillhole (uphole), Ψ, the direction cosines are given by the following relationships:

$$\begin{vmatrix} \ell_1 & \ell_2 & \ell_3 \\ m_1 & m_2 & m_3 \\ n_1 & n_2 & n_3 \end{vmatrix} = \begin{vmatrix} \cos\alpha & \sin\alpha\cos\Psi & -\sin\alpha\sin\Psi \\ -\sin\alpha & \cos\alpha\cos\Psi & -\cos\alpha\sin\Psi \\ 0 & \sin\Psi & \cos\Psi \end{vmatrix} \qquad \text{(D7A)}$$

Substituting the relevant equations from (D7) into equation D5 and collecting terms.

$$U = b_1J_1 + b_2J_2 + b_3J_3 + b_4J_4 + b_5J_5 + b_6J_6 \qquad \text{(D8)}$$

where U = total diametral deformation

$$b_1 = \sigma_x, \qquad b_4 = \tau_{xy},$$
$$b_2 = \sigma_y, \qquad b_5 = \tau_{yz},$$
$$b_3 = \sigma_z, \qquad b_6 = \tau_{zx},$$

(D9)

$$J_1 = f_1\ell_1^2 + f_2\ell_2^2 + f_3\ell_3^2 + f_4\ell_1\ell_3$$

$$J_2 = f_1m_1^2 + f_2m_2^2 + f_3m_3^2 + f_4m_1m_3$$

$$J_3 = f_1n_1^2 + f_2n_2^2 + f_3n_3^2 + f_4n_1n_3$$

$$J_4 = 2f_1\ell_1m_1 + 2f_2\ell_2m_2 + 2f_3\ell_3m_3 + f_4(\ell_1m_3+\ell_3m_1)$$
$$J_5 = 2f_1m_1n_1 + 2f_2m_2n_2 + 2f_3m_3n_3 + f_4(m_1n_3+m_3n_1)$$
$$J_6 = 2f_1n_1\ell_1 + 2f_2n_2\ell_2 + 2f_3n_3\ell_3 + f_4(n_1\ell_3+n_3\ell_1)$$

Equation D8 expresses the diametral deformation (U) of a drillhole as a linear function of bi. It may be noted that J is a function of the drillhole diameter and orientation (defined by the direction cosines), the orientation of the measured diametral deformation (θ) and the elastic constants (E and ν). Hence J is a known coefficient provided that the orientation of measurement and the elastic constants are specified. By determining U for six independent conditions and substituting the six sets of values in equation D8, six independent simultaneous equations are obtained. The six independent components of the stress tensor (b_i) can then be solved.

D.2.3 Least Squares Solution for the Stress Tensor

Although six independent determinations of U provide the minimum data required to calculate the six stress components, each measurement is subject to random effects as in all other types of field measurements. It is therefore desirable to make a number of sample measurements of U and to calculate from the collected data, an average value for each of the six stress components and an assessment of their accuracy.

The method of calculation is to apply the multilinear regression analysis to equation D5. The errors of b_i are minimized if the following conditions are satisfied.

$$\begin{aligned} &b_1\Sigma J_1^2 + b_2\Sigma J_1J_2 + b_3\Sigma J_1J_3 + \ldots. b_6J_1J_6 = \Sigma UJ_1 \\ &b_1\Sigma J_2J_1 + b_2\Sigma J_2^2 + b_3\Sigma J_2J_3 + \ldots. b_6J_2J_6 = \Sigma UJ_2 \\ &\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ &b_1\Sigma J_6J_1 + b_2\Sigma J_6J_2 + b_3\Sigma J_6J_3 + \quad b_6\Sigma J_6^2 = \Sigma UJ_6 \end{aligned} \tag{D10}$$

If we define

$$a_{ij} = \Sigma J_iJ_j \quad \text{and} \quad g_j = \Sigma UJ_j$$

$(i,j = 1, 2, 3 \ldots\ldots 6)$

Equation D10 can be written as

$$\begin{aligned} &b_1\,a_{11} + b_2\,a_{12} + b_3\,a_{13} \ldots + b_6\,a_{16} = g_1 \\ &b_1\,a_{21} + b_2\,a_{22} + b_3\,a_{23} \ldots + b_6\,a_{26} = g_2 \\ &\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ &b_1\,a_{61} + b_2\,a_{62} + b_3\,a_{63} \ldots + b_6\,a_{66} = g_6 \end{aligned} \tag{D11}$$

where $a_{21} = a_{12}$, $a_{31} = a_{13}$ etc.

The mathematical operation is to find a set of coefficients C_{ij} such that:

$$b_1 = C_{11}g_1 + C_{12}g_2 + C_{13}g_3 + \ldots\ldots C_{16}g_6$$
$$b_2 = C_{21}g_1 + C_{22}g_2 + C_{23}g_3 + \ldots\ldots C_{26}g_6 \qquad \text{(D12)}$$
$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$
$$b_6 = C_{61}g_1 + C_{62}g_2 + C_{63}g_3 + \ldots\ldots C_{66}g_6$$

where $C_{12} = C_{21}$, $C_{13} = C_{31}$, etc.

Expressing equations D11 and D12 in matrix form and defining the following matrices:

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} & \cdots & a_{16} \\ a_{21} & a_{22} & a_{23} & \cdots & a_{26} \\ - & - & - & - & - \\ a_{61} & a_{62} & a_{63} & \cdots & a_{66} \end{bmatrix} \qquad b = \begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \\ b_5 \\ b_6 \end{bmatrix}$$

$$C = \begin{bmatrix} C_{11} & C_{12} & C_{13} & \cdots & C_{16} \\ C_{21} & C_{22} & C_{23} & \cdots & C_{26} \\ - & - & - & - & - \\ C_{61} & C_{62} & C_{63} & \cdots & C_{66} \end{bmatrix} \qquad g = \begin{bmatrix} g_1 \\ g_2 \\ g_3 \\ g_4 \\ g_5 \\ g_6 \end{bmatrix}$$

Then equation D11 can be represented by

$$[A] \times [b] = [g] \qquad \text{(D13)}$$

then

$$[b] = [A]^{-1} \times [g] \qquad \text{(D14)}$$

$[A]^{-1}$ is the inverse of [A] and defining

$[C] = [A]^{-1}$ thus

$[b] = [C] \times [g]$, a matrix form of equation D12 (D15)

D.2.4 Statistical Interpretation of the Least Squares Solution

The parameters which are significant in the statistical interpretation of the least squares solution for the stress tensor are:

(a) The error sum of squares

$$\Sigma e^2 = \Sigma U^2 - \Sigma b_i g_i \quad (i = 1, 2....6) \tag{D16}$$

(b) The multiple correlation coefficient R, where

$$R^2 = 1 - \frac{\Sigma e^2}{\Sigma U^2} \tag{D17}$$

(c) The standard deviation, S, about the fitted regression line, equation D8

$$S = \left(\frac{\Sigma e^2}{(n-p)} \right)^{\frac{1}{2}} \tag{D18}$$

where n is the total number of U measurements
p is the number of b_i calculated from the data (the degree of freedom)

(d) The standard deviations of the stress components, b_i, are given by

$$\begin{aligned} S_{b_1} &= S\,(C_{11})^{\frac{1}{2}} \\ S_{b_2} &= S\,(C_{22})^{\frac{1}{2}} \\ &\text{- - - - - - - - -} \\ S_{b_6} &= S\,(C_{66})^{\frac{1}{2}} \end{aligned} \tag{D19}$$

where S is given by equation D18 and the coefficients C_{11}, C_{22} etc. are coefficients of [C] from equation D15.

D.2.5 Evaluation of Principal Stresses

With the six independent components of the stress tensor determined with respect to the x, y, z, co-ordinate system, it is possible to calculate the stress components with respect to any other cartesian co-ordinates. One transformation which will be of interest is the evaluation of the principal stresses and their directions from the six stress components.

If S_1, S_2 and S_3 are defined as the three principal stress components, there is a set of co-ordinate axes, 1, 2 and 3 such that the shear stresses $S_{12} = S_{23} = S_{31} = 0$. These axes are then the principal stress axes, the formulae for determining the principal stresses and their directions are given below.

The principal stresses are the three roots of the following cubic equation.

$$S^3 + 3BS^2 + 3CS + D = 0 \qquad \text{(D20)}$$

where

$$B = -(\sigma_x^* + \sigma_y + \sigma_z)/3,$$

$$C = (\sigma_x\sigma_y + \sigma_y\sigma_z + \sigma_z\sigma_x - \tau_{xy}^2 - \tau_{yz}^2 - \tau_{zx}^2)/3, \qquad \text{(D21)}$$

and

$$D = -\sigma_x\sigma_y\sigma_z - 2\tau_{xy}\tau_{yz}\tau_{zx} + \sigma_x\tau_{yz}^2 + \sigma_y\tau_{zx}^2 + \sigma_z\tau_{xy}^2$$

The three roots S_1, S_2, S_3 of equations D20 are found by calculating:

$$E = (B^2 - C)^{\frac{1}{2}},$$

$$F = -B^3 + (3BC - D)/2,$$

$$\cos 3A = \pm F/E^3,$$

$$S_1 = -B \pm 2E \cos A, \qquad \text{(D22)}$$

$$S_2 = -B \pm 2E \cos (A + 120^\circ),$$

$$S_3 = -B \pm 2E \cos (A + 240^\circ),$$

(where ± appears, use + if F is positive, use - if F is negative)

* compressive stresses are taken as -ve in this formulation

The direction cosines for principal direction 1 with respect to x, y, z are found from the following equations:

$$\begin{aligned}
&(S_1 - \sigma_x)\, l_1' - \tau_{xy} m_1' - \tau_{zx} n_1' = 0, \\
&-\tau_{xy} l_1' + (S_1 - \sigma_y) m_1' - \tau_{yz} n_1' = 0, \\
&-\tau_{zx} l_1' - \tau_{yz} m_1' + (S_1 - \sigma_z) n_1' = 0, \\
&(l_1')^2 + (m_1')^2 + (n_1')^2 = 1
\end{aligned} \qquad (D23)$$

The direction cosines for principal direction 2 are found from the same equations, except that each subscript 1 is replaced by a 2, and similarly for principal direction 3.

The bearing and inclination of any principal stress can be found as follows. It is easily shown that, for direction 1,

$$[\cos(\text{angle of inclination of } S_1)] \times [\cos(\text{bearing of } S_1)] = m_1', \qquad (D24)$$

$$[\cos(\text{angle of inclination of } S_1)] \times [\sin(\text{bearing of } S_1)] = l_1', \qquad (D25)$$

from which

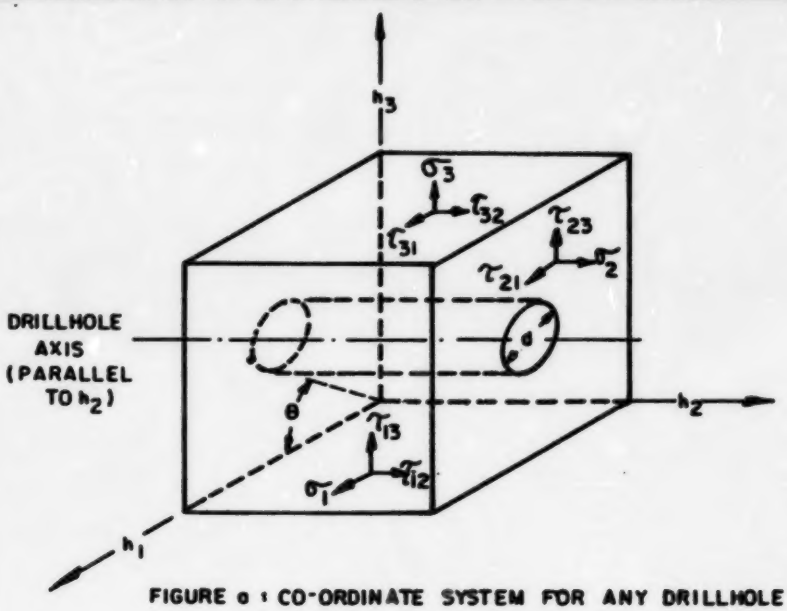
$$\tan(\text{bearing of } S_1) = l_1'/m_1'. \qquad (D26)$$

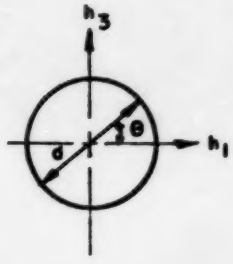
Given the bearing angle, the inclination can be found from equation D24 or D25.

In the case where the magnitudes of the principal stresses are close (ie. the stress system is fairly isotropic) the accuracy of the orientation calculation would reduce due to the small difference between the principal stresses.

CO-ORDINATE SYSTEMS FOR EVALUATION OF INSITU STRESSES

FIGURE D.1





θ = ORIENTATION OF DIAMETRAL DEFORMATION (MEASURED FROM h_1 AXIS)

FIGURE a : CO-ORDINATE SYSTEM FOR ANY DRILLHOLE

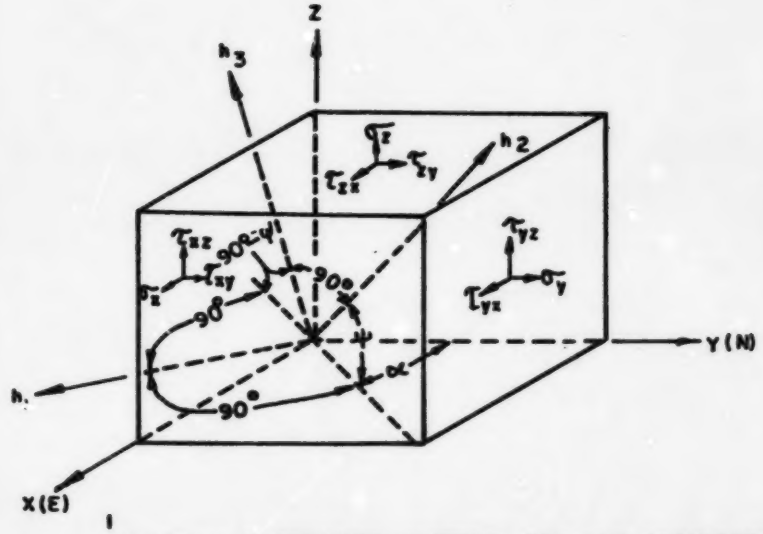


FIGURE b: CO-ORDINATE SYSTEMS FOR AN ARBITRARILY ORIENTED DRILL HOLE IN AN x, y, z CO-ORDINATE SYSTEM (x - EAST; y - NORTH; AND z - VERTICAL)

α - AZIMUTH OF DRILL HOLE

ψ - INCLINATION OF DRILL HOLE

NOTES

ALL CO-ORDINATE AXES ARE SHOWN IN THEIR POSITIVE DIRECTIONS.

Date JAN. 27, 1984
Project No. 831-1296

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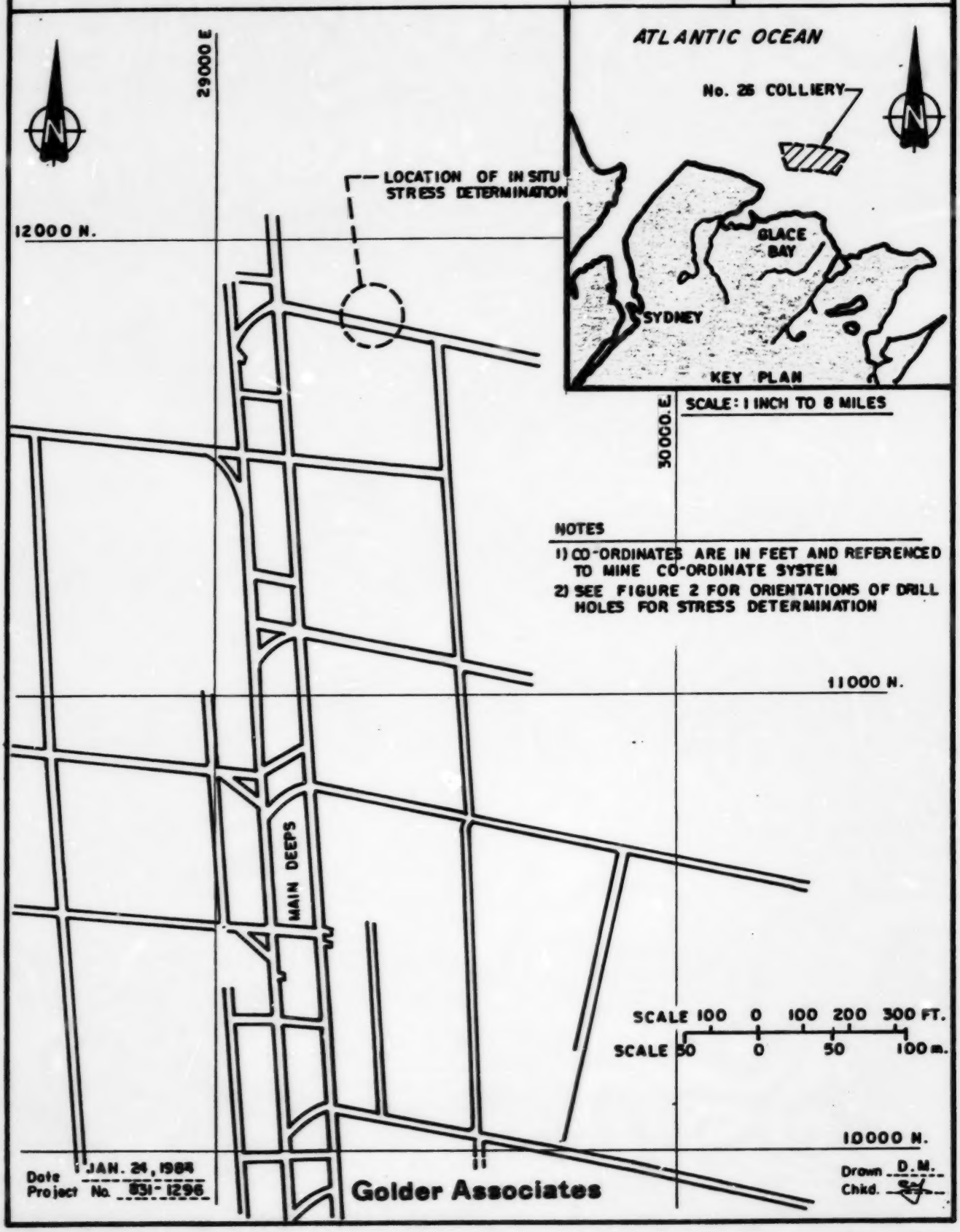
Drawn D.M.
Chkd.

Form G.A.-U.-4.

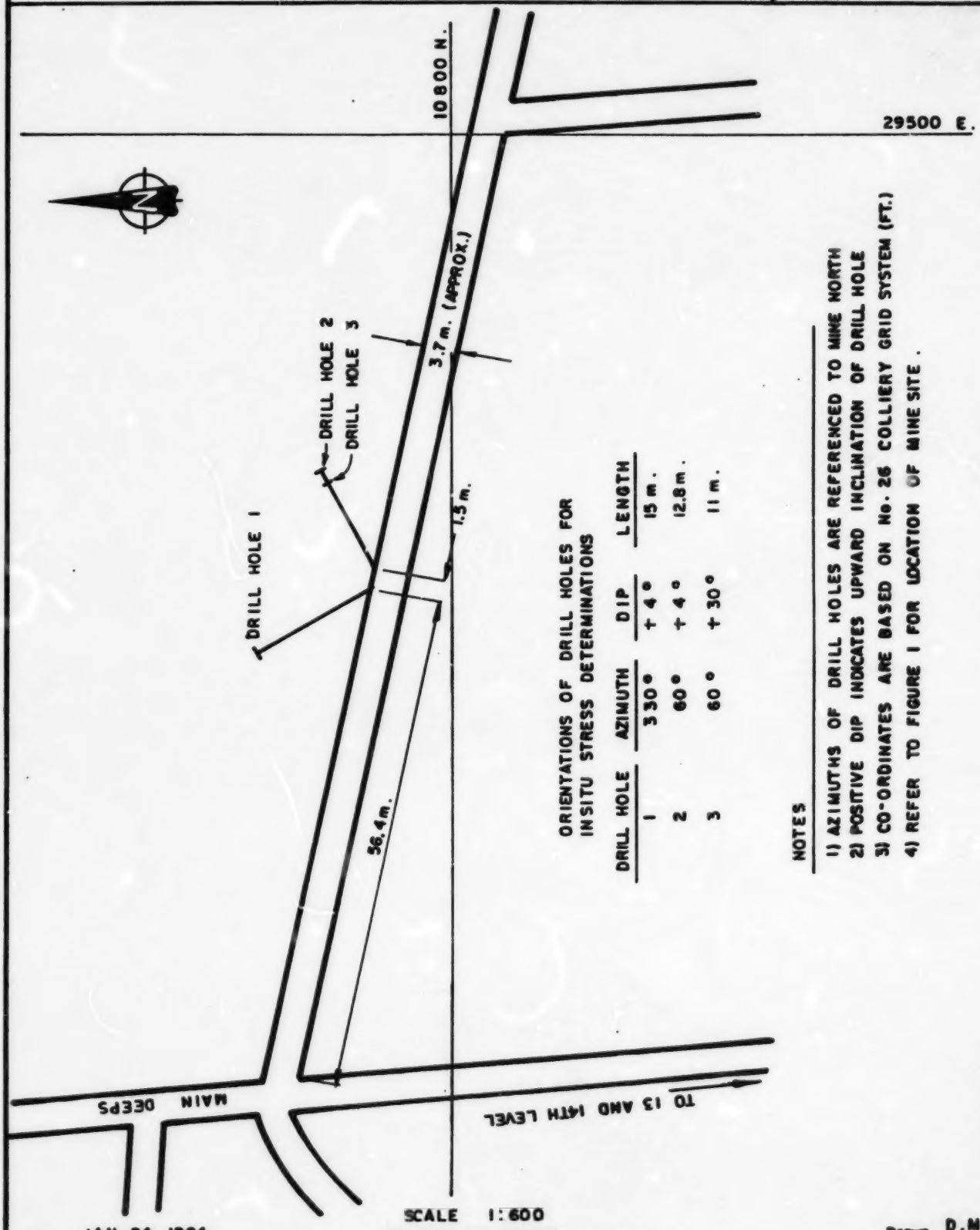
LOCATION OF INSITU STRESS DETERMINATION

FIGURE 1



LOCATIONS AND ORIENTATIONS OF DRILL HOLES FOR STRESS DETERMINATION

FIGURE 2



ORIENTATIONS OF DRILL HOLES FOR INSITU STRESS DETERMINATIONS

DRILL HOLE	AZIMUTH	DIP	LENGTH
1	330°	+4°	15 m.
2	60°	+4°	12.8m.
3	60°	+30°	11 m.

NOTES

1) AZIMUTHS OF DRILL HOLES ARE REFERENCED TO MINE NORTH
2) POSITIVE DIP INDICATES UPWARD INCLINATION OF DRILL HOLE
3) CO-ORDINATES ARE BASED ON No. 26 COLLIERY GRID SYSTEM (FT.)
4) REFER TO FIGURE 1 FOR LOCATION OF MINE SITE.

SCALE 1:600

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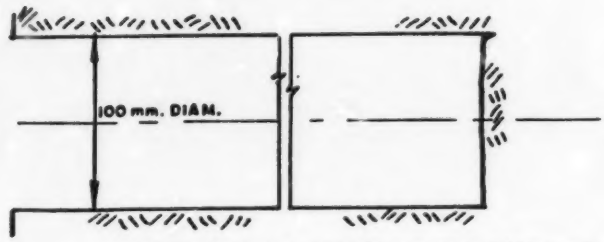
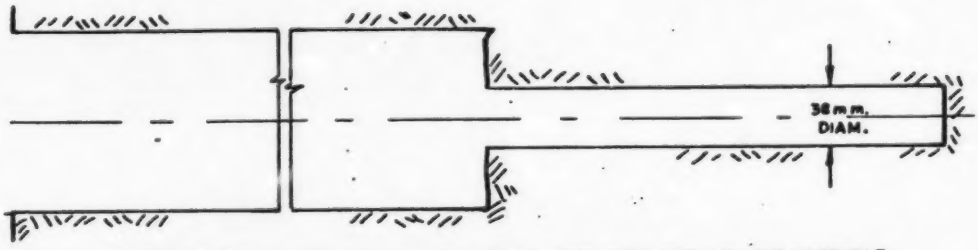
Drawn D.M
Chkd. CL

STRESS MEASUREMENT BY OVERCORING METHOD

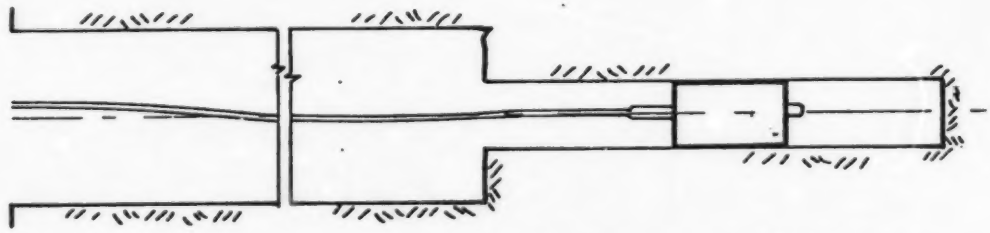
FIGURE 3



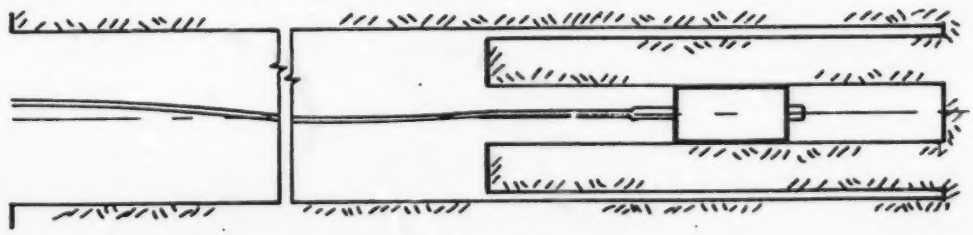
(A) 100mm DIAMETER BOREHOLE DRILLED TO THE DEPTH AT WHICH THE STRESS IS TO BE DETERMINED.



(B) EXT BOREHOLE DRILLED FOR 500mm TO 600mm INTO THE END OF THE BOREHOLE.



(C) CSIRO OR USBM BOREHOLE GAUGE INSTALLED IN CENTRAL SECTION OF EXT BOREHOLE.



(D) EXT BOREHOLE OVERCORED USING A 100 mm DIAMETER THINWALL BIT.

NOT TO SCALE

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FIGURE 4. USBM DEFORMATION GAUGE

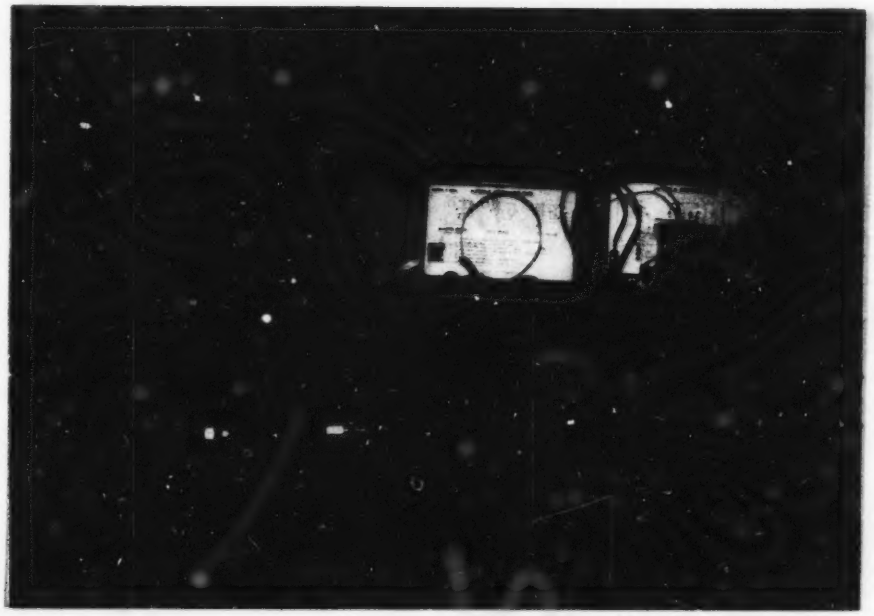


FIGURE 5. SET-UP FOR BIAXIAL TEST

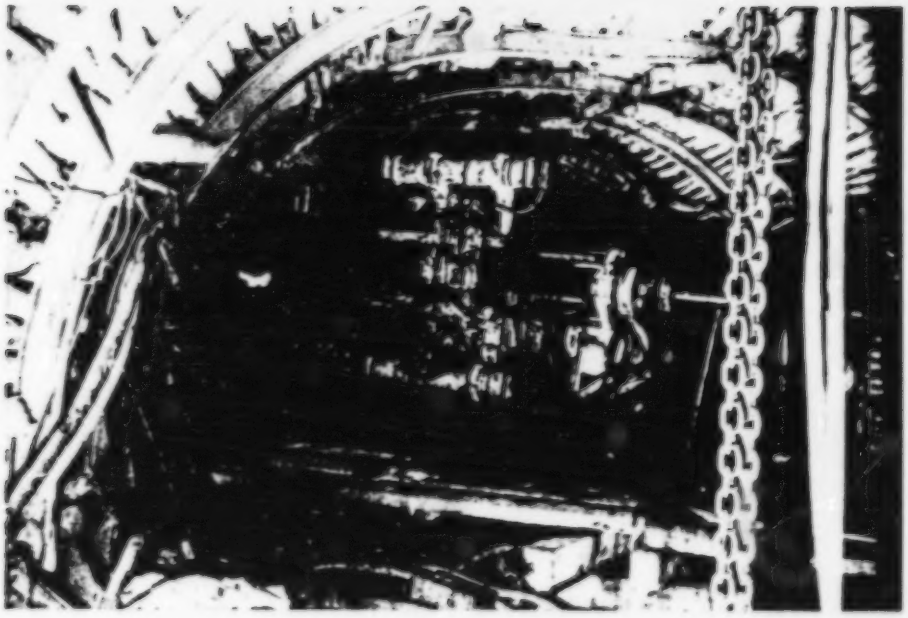
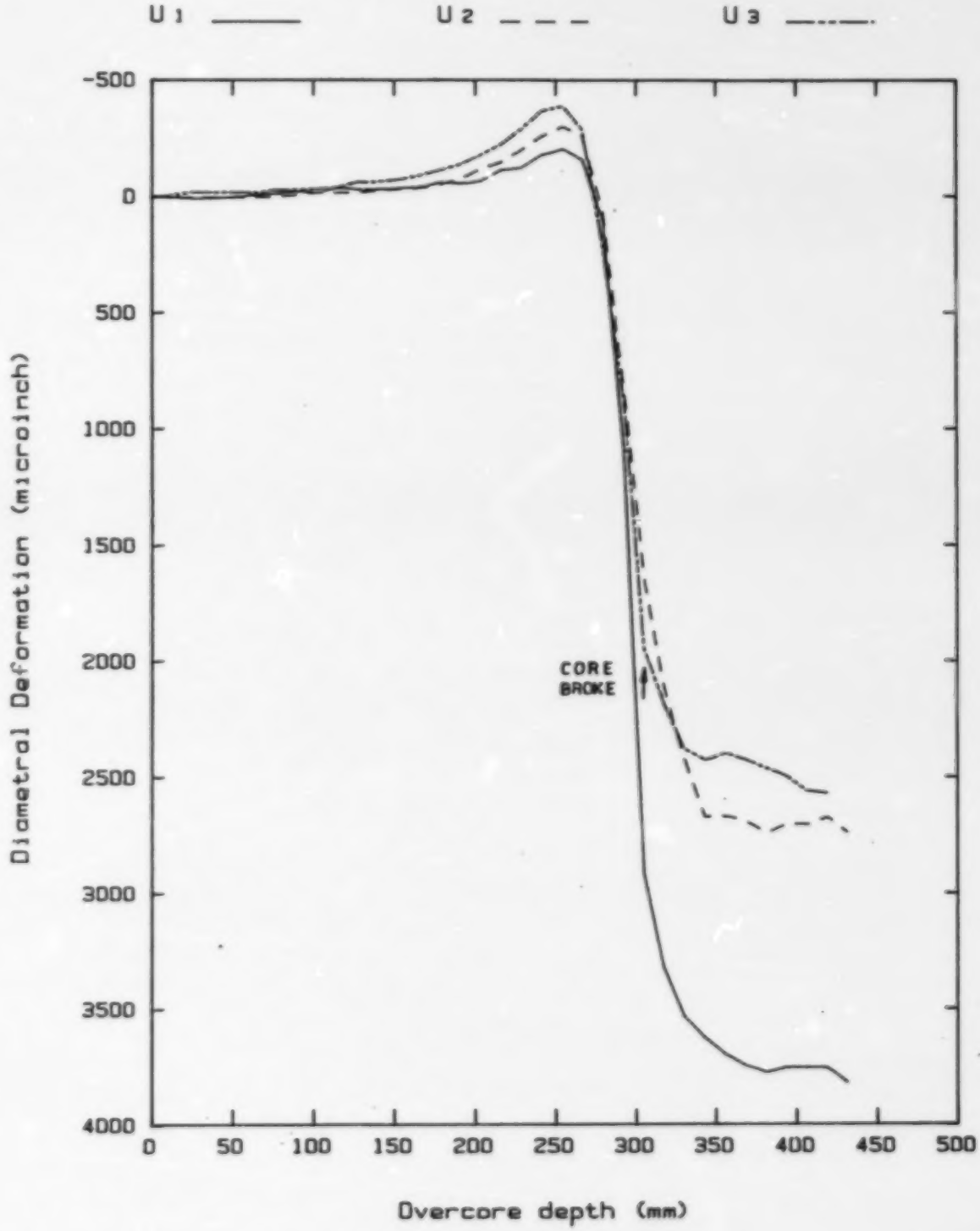


FIGURE 6. GENERAL ARRANGEMENT OF DRILL RIG FOR INSITU STRESS MEASUREMENT

INSITU STRESS MEASUREMENTS - USBM TEST No. 2
No. 26 Colliery Hole No. 1 Depth 11.73m

FIGURE 7



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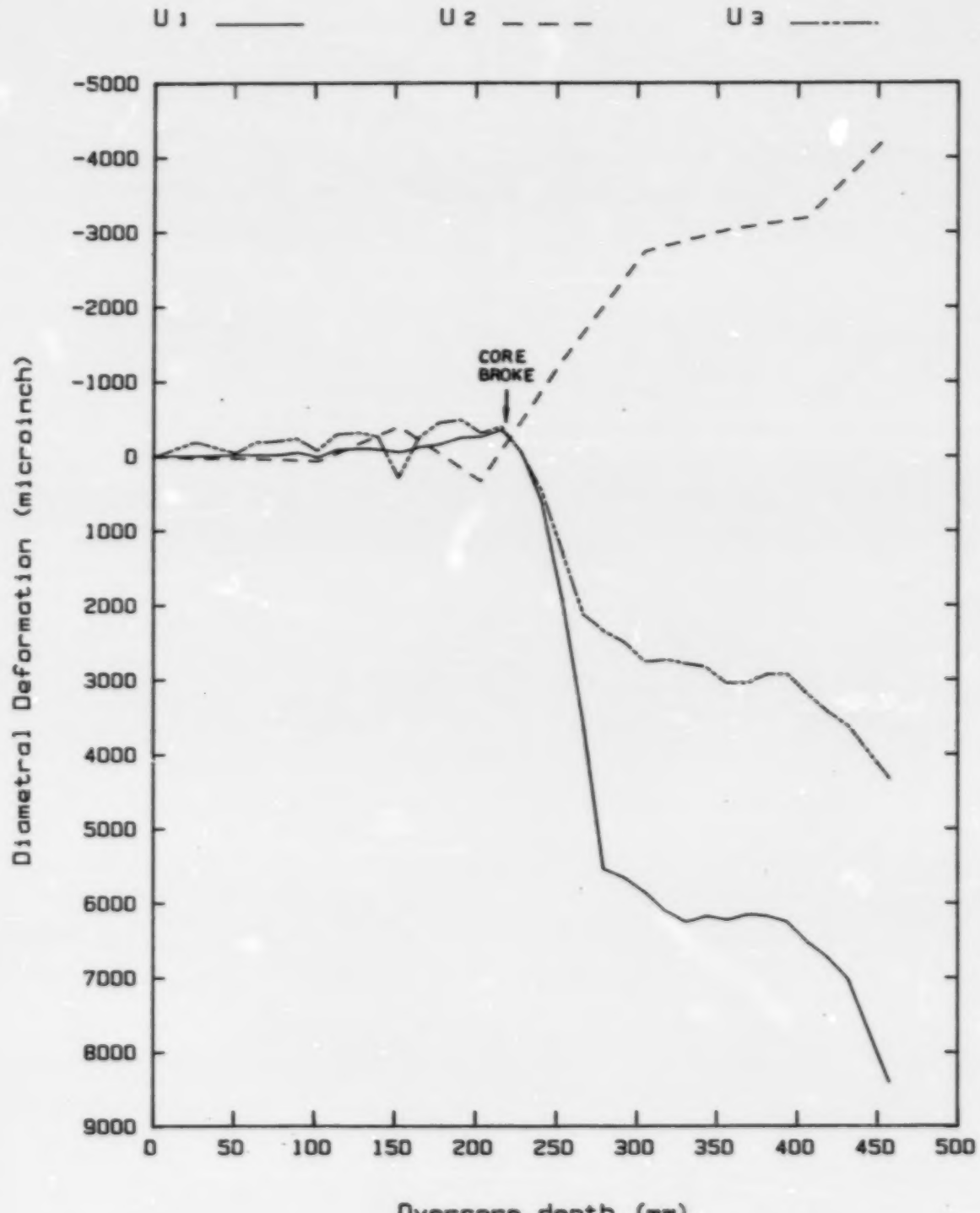
INSITU STRESS MEASUREMENTS - USBM TEST No. 3
No. 26 Colliery Hole No. 1 Depth 12.75m

FIGURE 8



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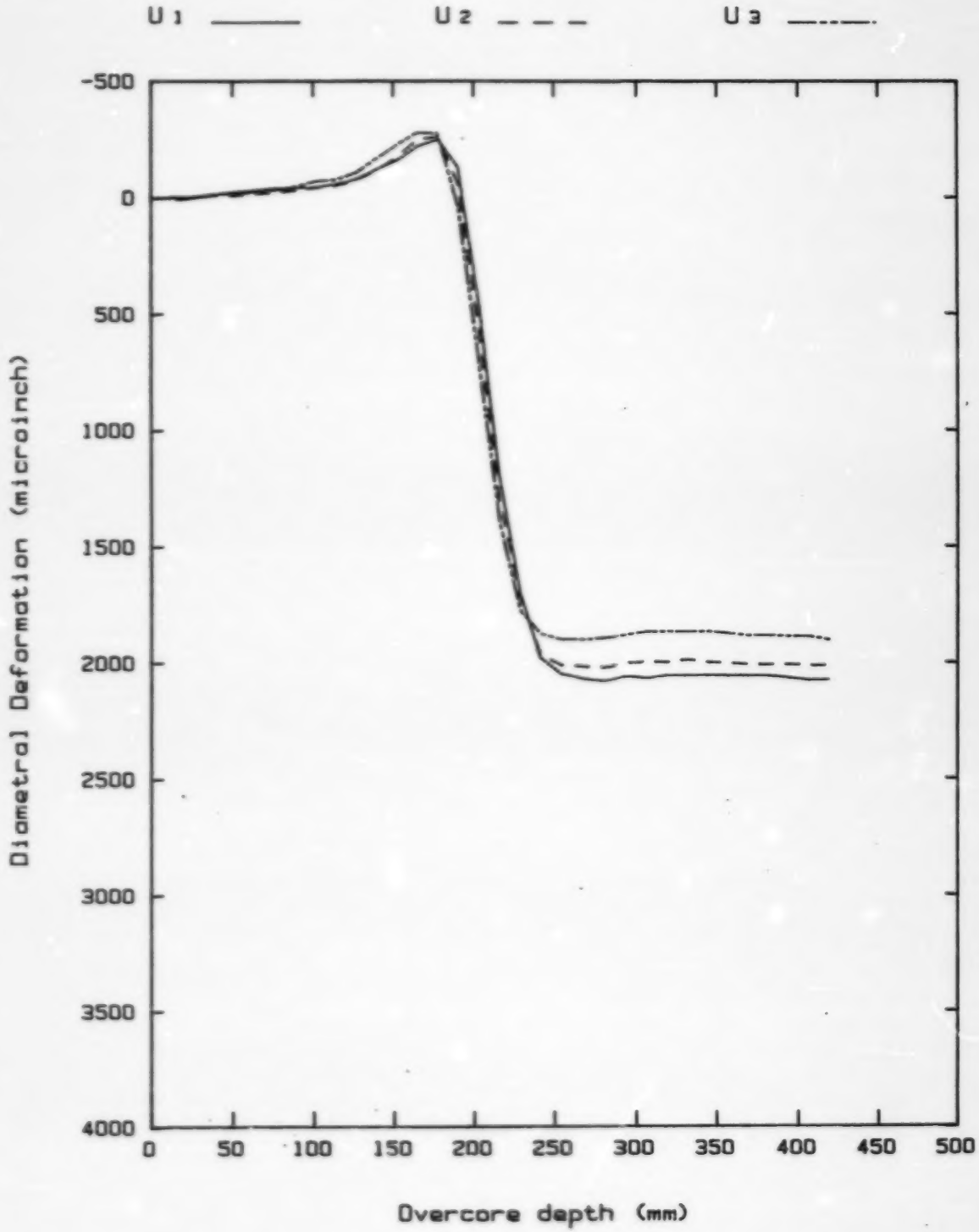
INSITU STRESS MEASUREMENTS - USBM TEST No. 4
No. 26 Colliery Hole No. 1 Depth 15.14m

FIGURE 9



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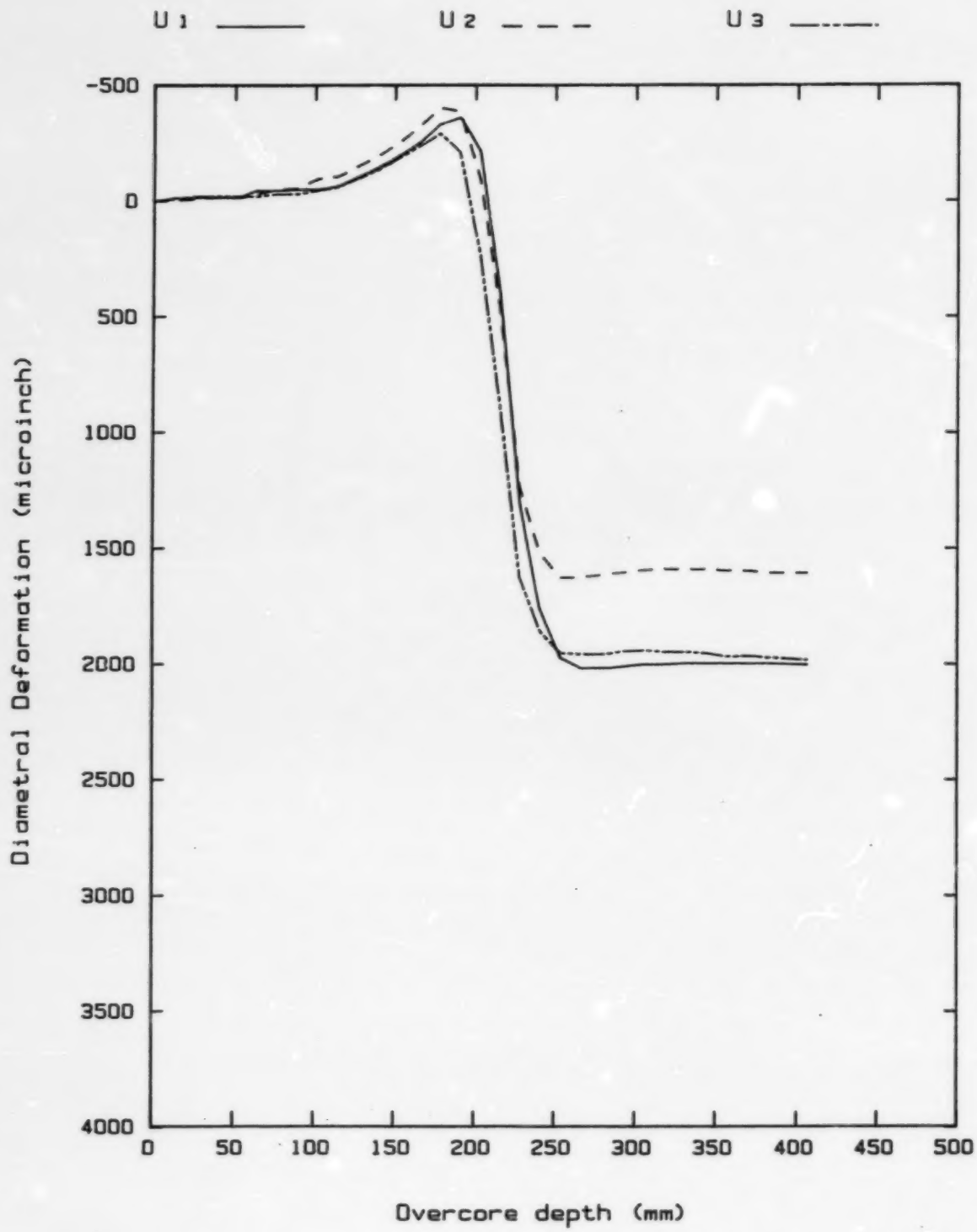
INSITU STRESS MEASUREMENTS - USBM TEST No. 5
No. 26 Colliery Hole No. 2 Depth 11.18m

FIGURE 10



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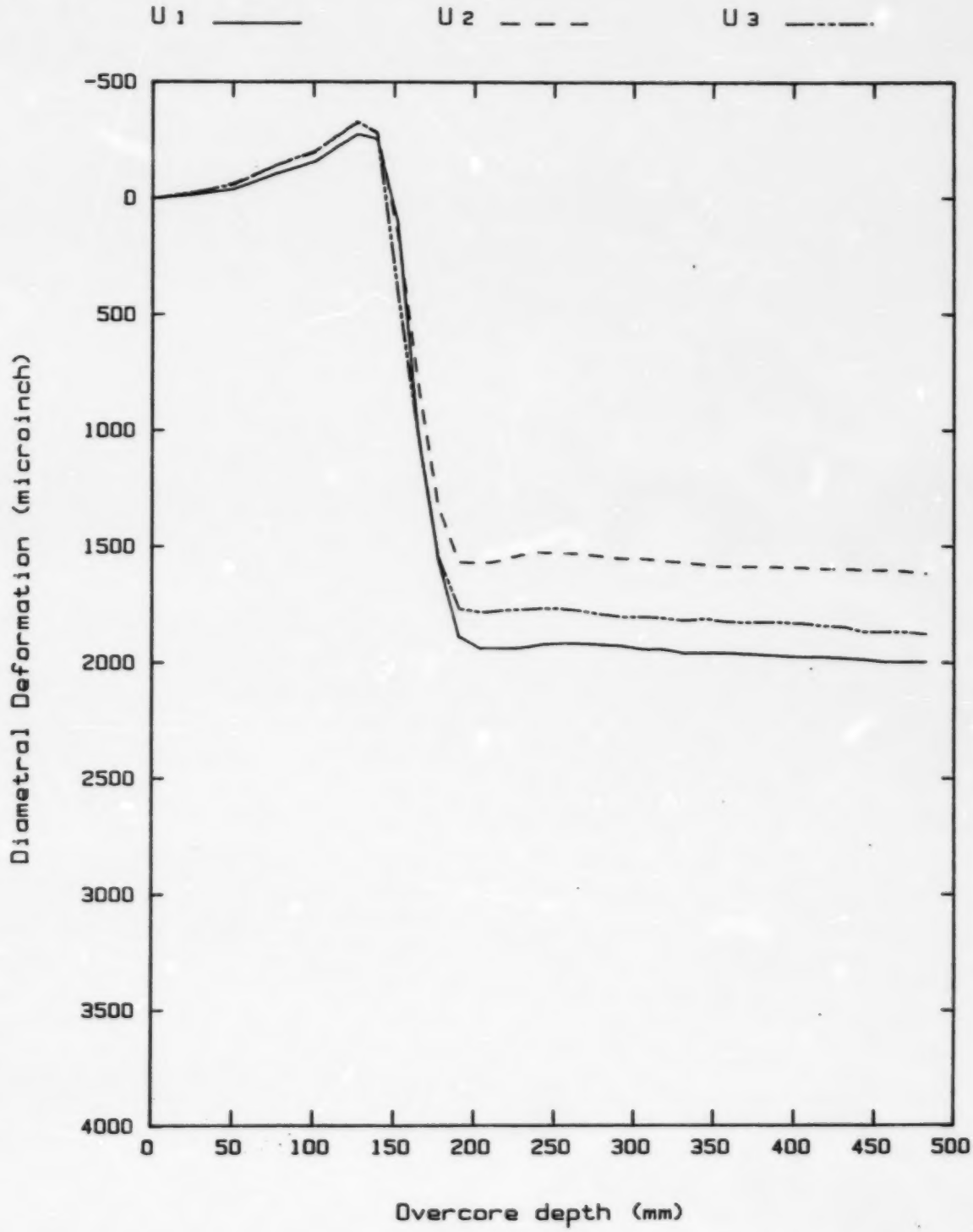
INSITU STRESS MEASUREMENTS - USBM TEST No. 6
No. 26 Colliery Hole No. 2 Depth 11.84m

FIGURE 11



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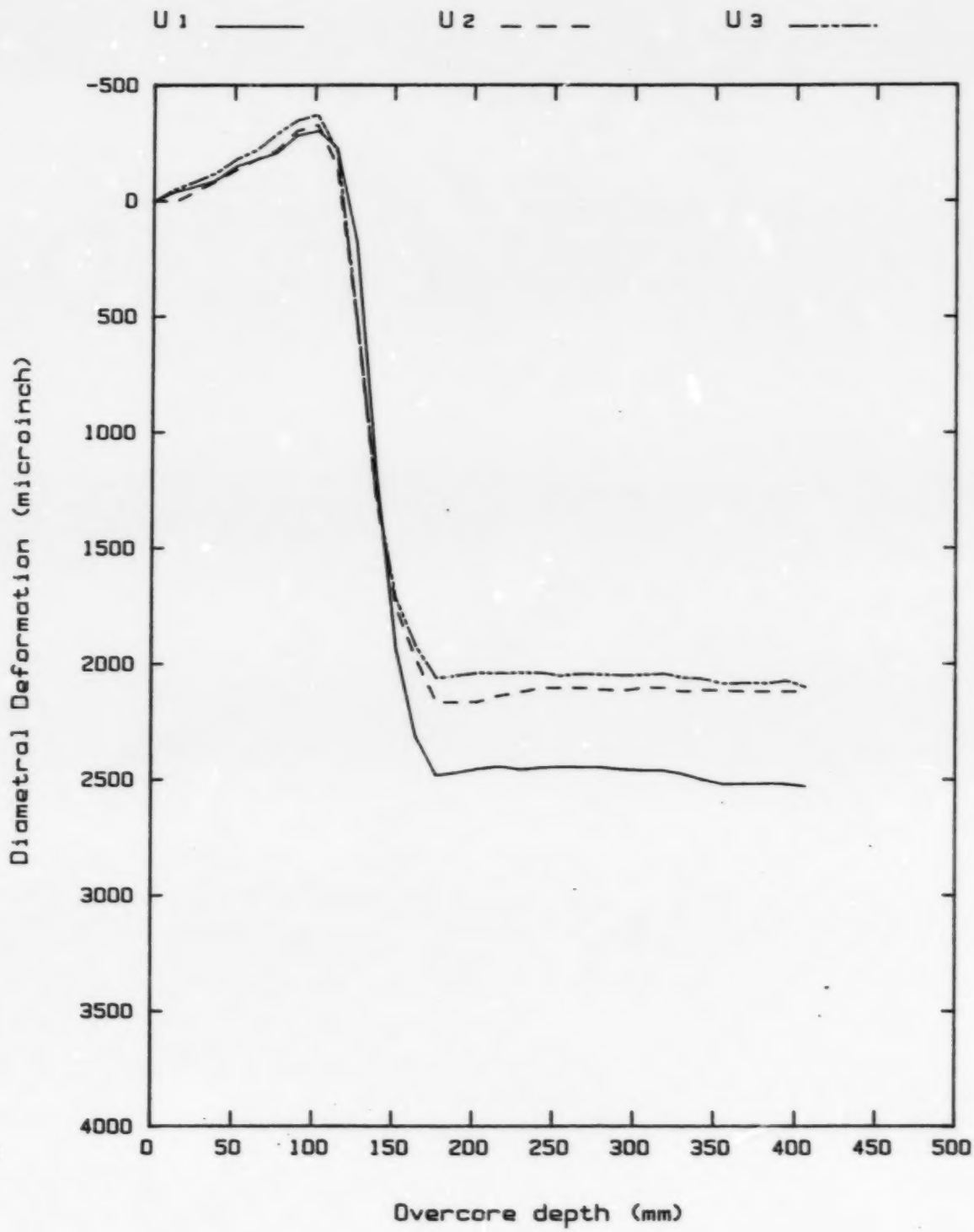
INSITU STRESS MEASUREMENTS - USBM TEST No. 7
No. 26 Colliery Hole No. 2 Depth 12.5m

FIGURE 12



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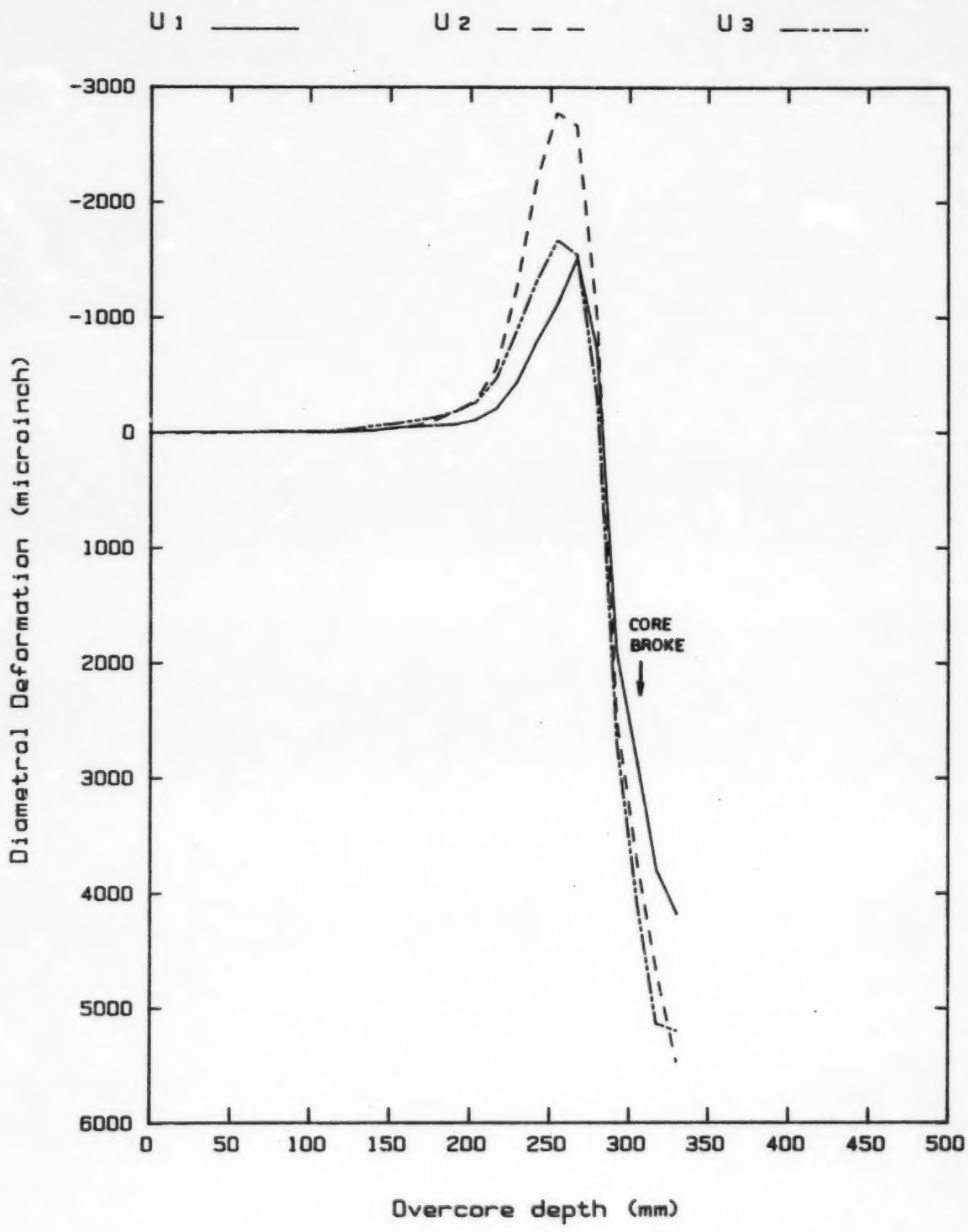
Chkd. GJ

Form U.S.B.M.

INSITU STRESS MEASUREMENTS - USBM TEST No. 8
No. 26 Colliery Hole No. 3 Depth 9.4m

FIGURE 13



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Chkd. SAV

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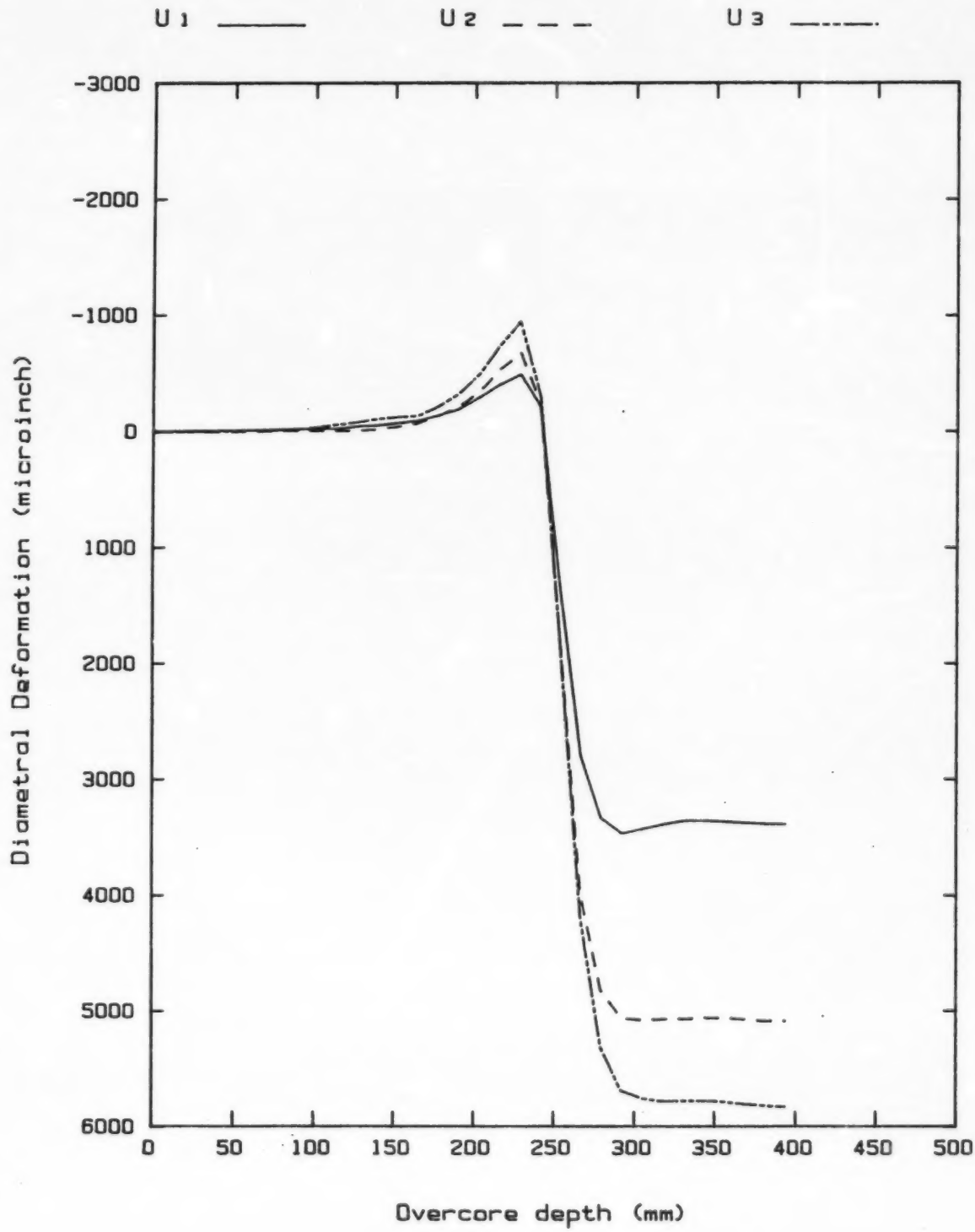
INSITU STRESS MEASUREMENTS - USBM TEST No. 9
No. 26 Colliery Hole No. 3 Depth 11.15m

FIGURE 14



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Chkd.

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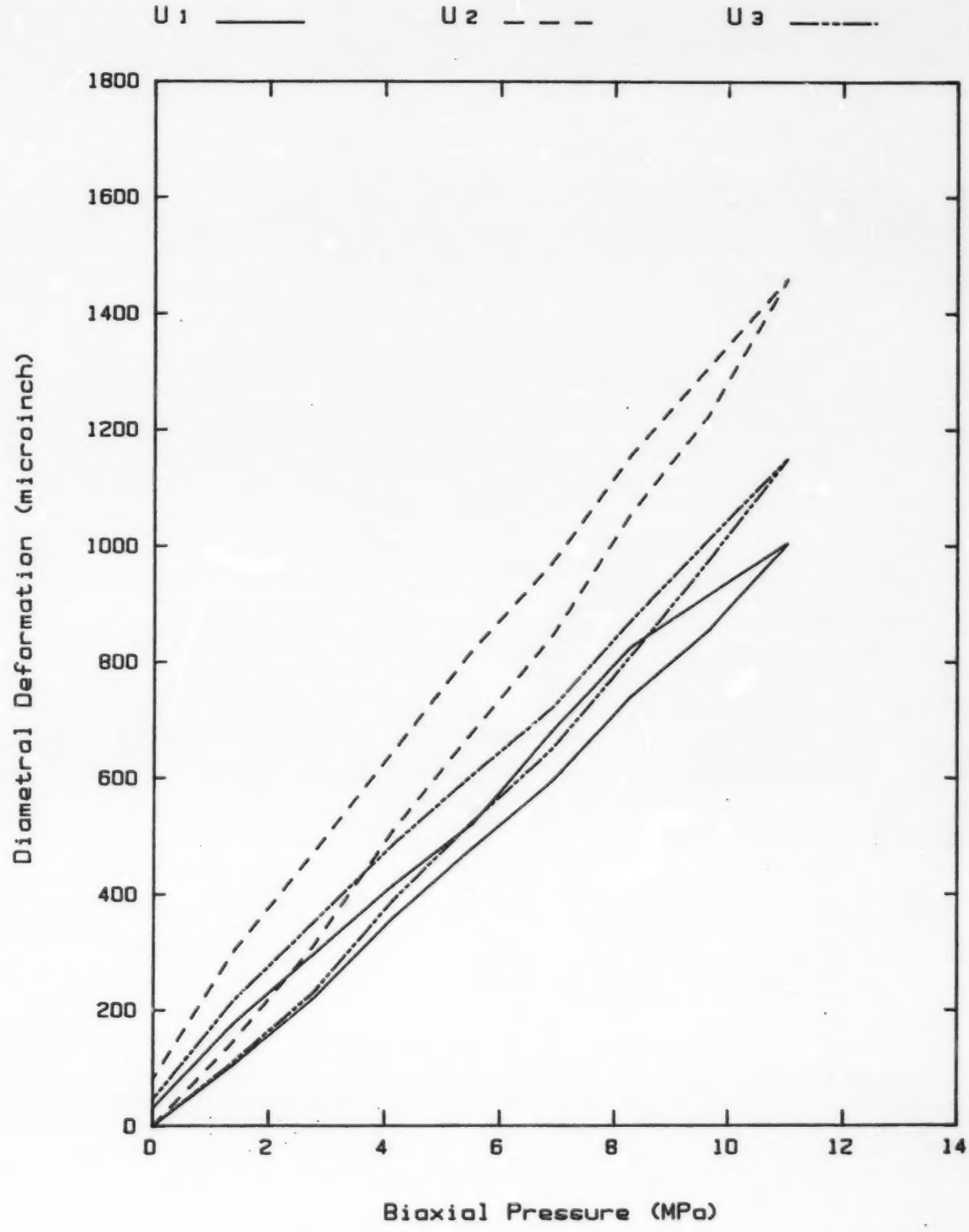
BIAXIAL TEST No. 1 (Siltstone)
Drillhole No. 1 Depth 12.69m

FIGURE 15



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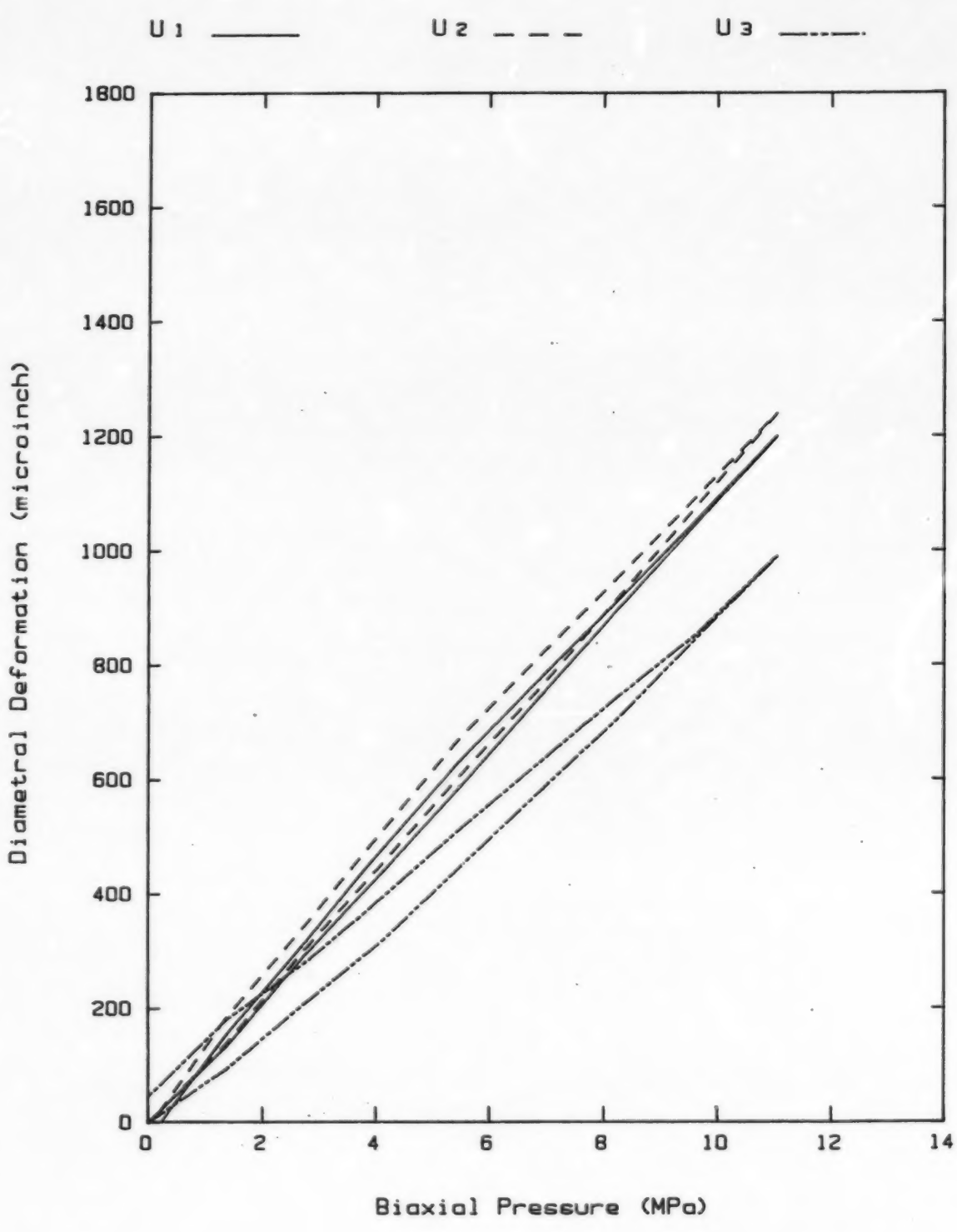
BIAXIAL TEST No. 2 (Siltstone)
Drillhole No. 1 Depth 13.8m

FIGURE 16



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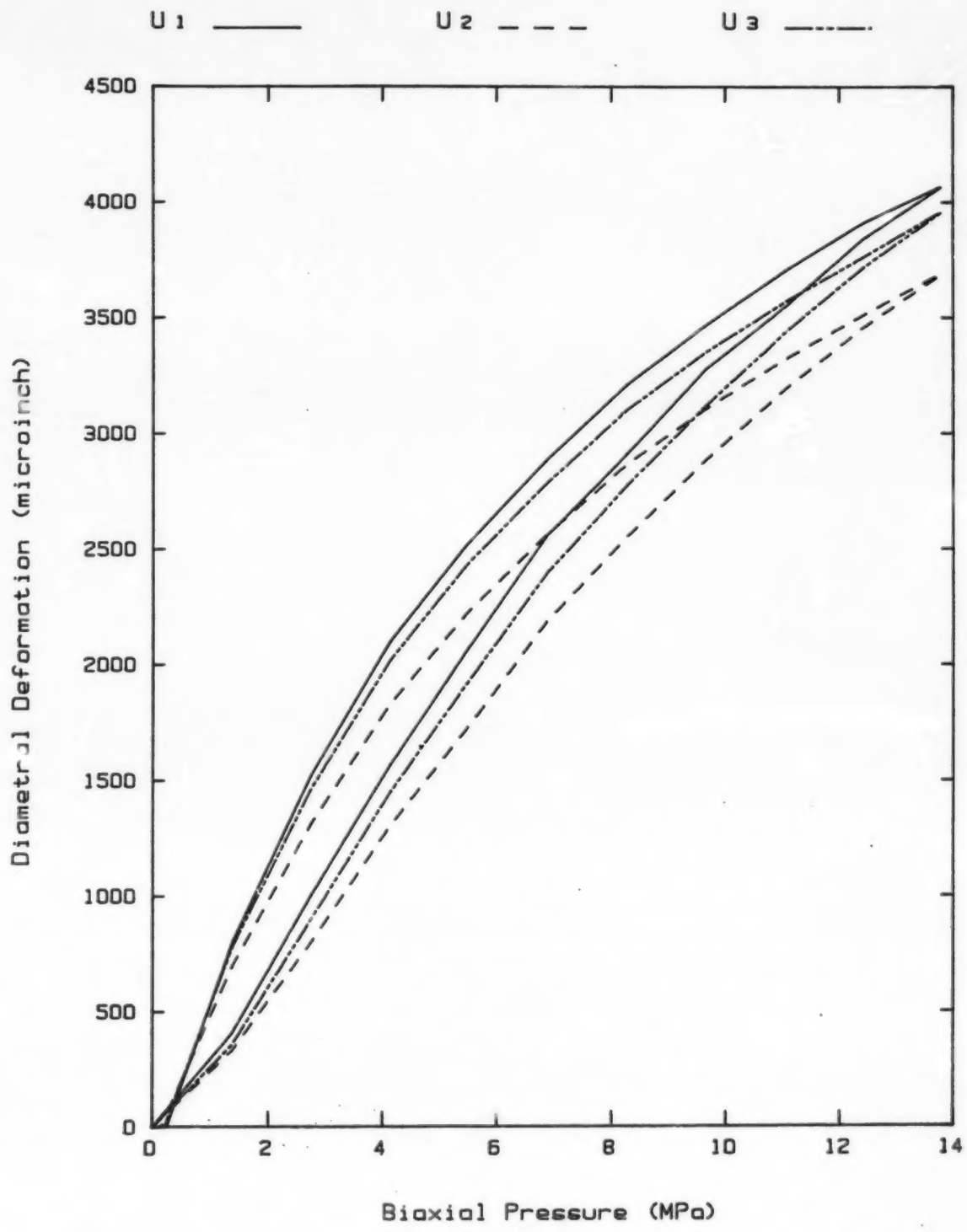
BIAXIAL TEST No. 3 (Sandstone)
Drillhole No. 3 Depth 11.15m

FIGURE 17



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POOR

QUALITY

ORIGINAL